ISSUE PAPER “G” - v.5.(final)

COLD CLIMATE CONSIDERATIONS FOR SURFACE WATER MANAGEMENT

Date: January 13, 2005 (revised Jan. 17, 2005)

To: Minnesota Stormwater Manual Sub-Committee

From: EOR and CWP

PREFACE

After considering the material that was available for the consultant team and the variety of questions that arise concerning the special needs of cold climate water managers, this Issue Paper was assembled with two audiences in mind. First, of course, is the MSC, which will be responsible for putting out a useable product. Secondly, however, is the Minnesota stormwater practitioner audience that continually asks for more information on the nature of the cold climate problem and possible solutions for it. It is our intent to include much of the content in this Issue Paper either directly in the text of the Manual when cold climate is discussed or to put the entire paper in the appendix for reference by those interested in the topic.

Additionally, some of the issues identified below might not be able to be resolved at this point in the MSC deliberations. They are presented, however, to set the stage for later discussion and resolution. For example, Issues 5-7 raise topics that should be thought about for future Phase II permit amendments. The intent in this paper is to capture the issue and discuss its importance in the eyes of the MSC.

I. ISSUES RELATED TO COLD CLIMATE RUNOFF MANAGEMENT

The following issues are addressed in this paper:

ISSUE #1: The RFP and the EOR/CWP response proposal stressed that the Minnesota Stormwater Manual should focus some attention on cold climate conditions and the pollutants associated with them. As an outcome of this direction:

- Should higher levels of treatment (i.e., pollutant removal) be recommended, perhaps in an SWPPP, based on land use, snow management plans, and anticipated pollutant loads of priority pollutants (sediment, chlorides, nutrients)?
- Should higher levels of treatment be recommended based on receiving water quality or proximity to drinking water source protection areas?

ISSUE #2: Should the above sequence of management steps be suggested in the Manual as a logical progression of steps toward meltwater runoff management?

ISSUE #3: Both of the previous Issue Papers ("A" and "B") recognized infiltration based BMPs as desirable for Minnesota. The potential introduction of Cl and the possible loss of effective performance during cold weather means that infiltration-based systems should be used carefully as a winter practice.

- Should they continue to be promoted, but with very clear cautions and restrictions, such as sizing for a larger design event to capture and treat during melt?
- Should a more prescriptive treatment train be recommended for infiltration practices, such as oversized pretreatment, possible use of proprietary sediment removal, or further down-gradient treatment if needed for by-pass?

ISSUE #4: Should the unified sizing criteria for ponding (if and when adopted) include adaptations that would account for less effective cold weather treatment or should we view any improvement through adaptation as an extra benefit outside of the criteria?

ISSUE #5: Should Minnesota be doing more to explore alternatives to the use of NaCl and ways to lower the impact of salt on our receiving waters?

ISSUE #6: How should the Manual interact with the Phase II program to better address winter construction practices? Should the Manual contain specific guidance on winter construction practices that would minimize water quality degradation?

<u>ISSUE #7:</u> Should Minnesota develop guidelines for the proper operation of snow dump sites?

<u>ISSUE #8:</u> Should low impact development techniques be promoted in the Minnesota Stormwater Manual as a viable meltwater (in addition to rainfall runoff) management approach?

<u>ISSUE #9</u> - Do we know enough about the behavior of snow and meltwater to adequately design and operate runoff management systems adapted specifically for cold climate use? Is standard BMP technology sufficient to accomplish this task? Should the Manual be a vehicle to get guidance out to users on how BMP adaptations can be made to achieve water quality improvements during snowmelt events?

<u>ISSUE #10</u> - Can routine rainfall runoff BMPs be adapted to work under the severe cold weather conditions experienced in Minnesota? If so, should the state expect these to be part of routine planning for management of runoff?

II. REVIEW OF WHY COLD CLIMATE CONDITIONS IMPACT RUNOFF MANAGEMENT

Background

Given Minnesota's climate and the importance of snowmelt in stormwater quality, the Minnesota Stormwater Manual must offer users practices and engineering criteria that are adapted to cold climate conditions. This issue paper will incorporate national and international research and experience on stormwater practices maintained in cold climate regions, and will present principles for adapting BMPs to provide effective pollutant removal and runoff control during cold-weather months. The paper will also introduce some recent findings from within Minnesota on the impact of climate change on stormwater and meltwater runoff. This will supplement the information currently contained in Chapter 5 of MPCA's *Protecting Water Quality in Urban Areas* (the "Blue Book" and 2000 update).

The basic problems that must be addressed by Minnesota stormwater managers are that the runoff from snowmelt has characteristics different than those of rainfall runoff, and that BMP design criteria generally address rainfall runoff, but might not work well during cold periods. This becomes a major problem because a substantial percentage of annual runoff volume and loading can come from snowmelt in years when snowfall is high.

Because of the experience of EOR and CWP staff in cold climates and the number of their publications on the topic, portions of previously published text have been adapted for this Issue Paper. The material has been updated and reviewed relative to the current needs for the Manual, but much of the information has been reiterated because of its relevance.

This Issue Paper also draws from several cold climate specialty conferences and publications that are referenced throughout the paper and in Appendix A. Specifically, these include:

- *The International Conference on Urban Hydrology Under Wintry Conditions*, Narvik, Norway, March 19-21, 1990
- *Stormwater BMP Design Supplement for Cold Climates*, Center for Watershed Protection (Caraco and Claytor), 1997
- *Urban and Highway Snowmelt: Minimizing the Impact on Receiving Water*, Water Environment Research Foundation, 1999
- *Urban Drainage in Cold Climates*, Vol. II of *Urban Drainage in Specific Climates*, International Hydrological Programme, UNESCO, 2000
- *First International Conference on Urban Drainage and Highway Runoff in Cold Climate(s)*, Riksgränsen, Sweden, 2003.
- *An International Conference on Stormwater Management in Cold Climates*, Portland, Maine, 2003

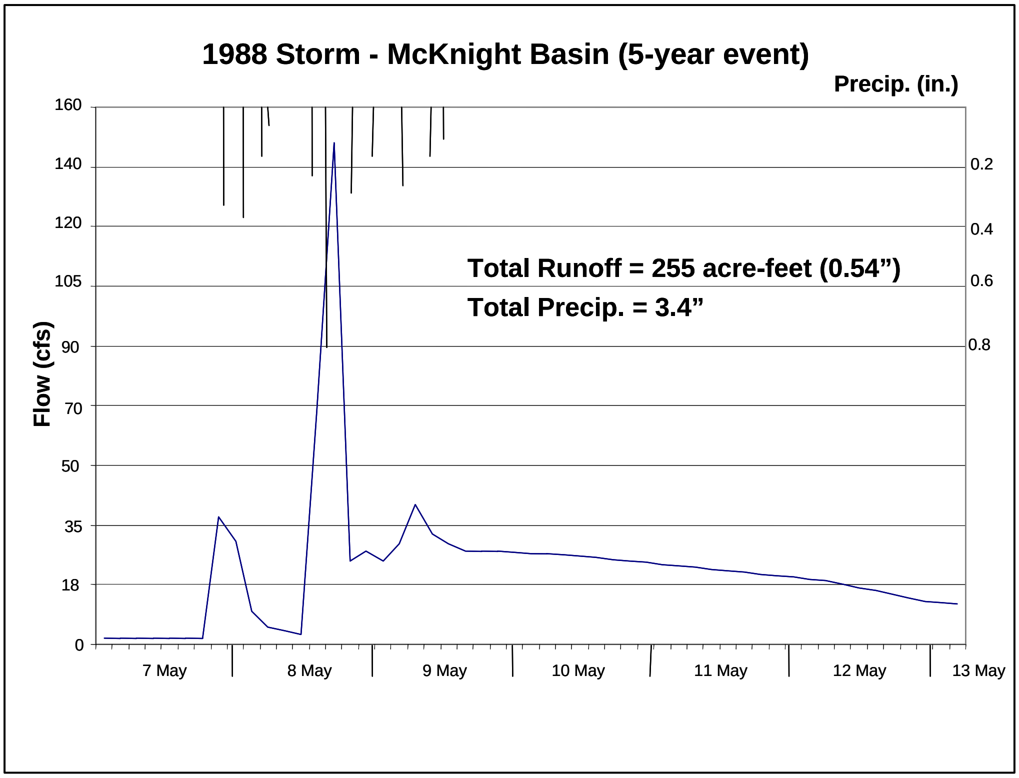
Nature of the Cold Climate Problem

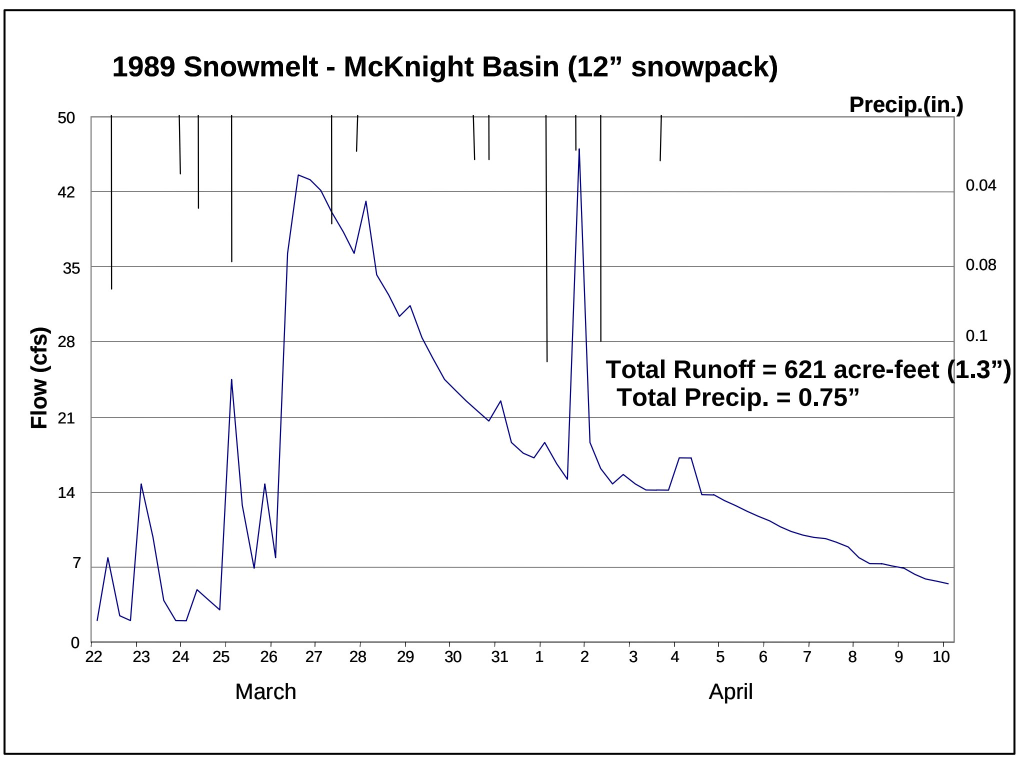
Hydrology of Melt. The heart of the problem with snowmelt runoff is that water volume in the form of snow and ice builds for several months and suddenly releases with the advent of warm weather in the spring or during short interim periods all winter long. The interim melts generally do not contribute a significant volume of runoff when compared to the large spring melt. Figure 1 shows an example of how this can be important in Minnesota. This comparison shows the runoff from a 3.4 inch rainfall over 36 hours (2.3 inches in 24 hours is about a one-year frequency event) on an urban Ramsey County watershed compared to an above normal snowpack (about 12 inch vs. "normal" at about 7 inches) melt event over about two weeks during which an additional 0.75 inches of rain fell. Note that although the snowmelt peaks are substantially less than the rainfall, the total event volume, although it occurs over a much longer period, is more than double. The total amount of rainfall runoff at this site for April-November 1988 was 421 acre-feet. Although this was a dry year, this annual volume is substantially less than the 621 acre-feet that resulted from the 1989 snowmelt.

Although this is a specific example and it involves a little more snow than usual, it is typical of Minnesota snowmelt runoff events. The reason for concern is that the daily amount of runoff in need of treatment in both cases (see Figure 1) is about 0.1" of runoff (0.54" over five days and 1.3" over about two weeks). In other words, ignoring the contribution of these large spring melts to the annual runoff and pollution loading analysis could be a major omission in a watershed analysis. This type of comparison also shows why facility design is critical to the proper quantity and quality management of this meltwater.

This behavior of seeing a major portion of the annual runoff occur during the relatively short period in the year when the snowpack melts is typical of cold climates. Factors influencing the nature of this melt and the speed with which it occurs include solar radiation, the distribution of snow cover, the addition of de-icing chemicals to the pack, and the amount of freeze-thaw cycling. Each of these processes can be modeled and predictions generated on the volume of water that will be available for wash-off. The development of better distributed models that describe the details of snow accumulation and subsequent melting is not within the scope of the Minnesota Manual, but is one of the most significant areas of emerging research, particularly in Scandinavia. Excellent summaries of snow accumulation and melt processes, and the extensive work in this field, are contained in Chapter 2 (A. Semadeni-Davies and L. Bengtsson) and Chapter 3 (J. Milina) of the UNESCO 2000 report on *Urban Drainage in Cold Climates.*

Figure 1. Volume Comparison of Rainfall Versus Snowmelt Hydrographs (Oberts *et al*., 1989)





The source area for snowmelt plays a critical role in both the hydrologic and water quality character of snowmelt runoff, as shown in Figures 2a-c. Roadways and large paved surfaces (Figure 2a) like commercial parking lots are the direct recipients of fast and efficient snow removal. This can occur by plowing, which can include total site removal or relocation off of the surface, and/or chemical-induced (salt) melting. Because of the need to promote safety, obtaining an ice- and snow-free surface is a focal point for winter management of these surfaces. As a result, these surfaces generate numerous loading events every time it snows or even in anticipation of a snowfall, since pre-icing application of salt can be a common practice. By the time the major spring melt occurs, many of these surfaces are free of snow and ice. However, in many instances the snow that has been removed is piled or plowed close to the surface and flows onto it, at which time it becomes part of the urban drainage system or is stored in a location where it immediately enters the drainage system upon melt. These road and parking surfaces can be a significant source of many of the most contaminating pollutants associated with urban runoff, as discussed in the next section.

Figure 2b shows the second category of importance to snowmelt runoff and the area that is generally the most significant source of poor water quality during a melt. This is the area immediately adjacent to the roadway or parking surface. Because snow is plowed and piled in these areas, they accumulate both equivalent water volume and pollutants for an extended period of time over the winter. This material is then available for release and migration over a several week period in the spring, in a manner described in the next section. This critical area is usually contained within about 25 feet of the paved surface and easily flows to the storm drain system as it melts. Sometimes, as in commercial parking or roadside piles, the snow is actually sitting on an impervious surface.

The final contributing area to meltwater runoff is the less developed residential, open space, low density area typical of suburban watersheds (Figure 2c). Snowmelt from these areas can be large contributors of meltwater volume, but the quality of the melt is better than from roadways and parking areas. Typically a fair amount of the initial meltwater soaks into the ground and can continue to do so as long as the rate of melt does not exceed the infiltration capacity of the soil (see discussion in Issue Paper “B”). If sufficient snowpack is available, saturation can occur, leading to this portion of the watershed acting as an impervious surface.

Figures 2a-c. Photos of Different Source Areas for Melt Generation.

2a. Direct Paved Surfaces with Heavy Traffic.

2b. Nearby Areas of Snow accumulation from Distribution/Plowing.

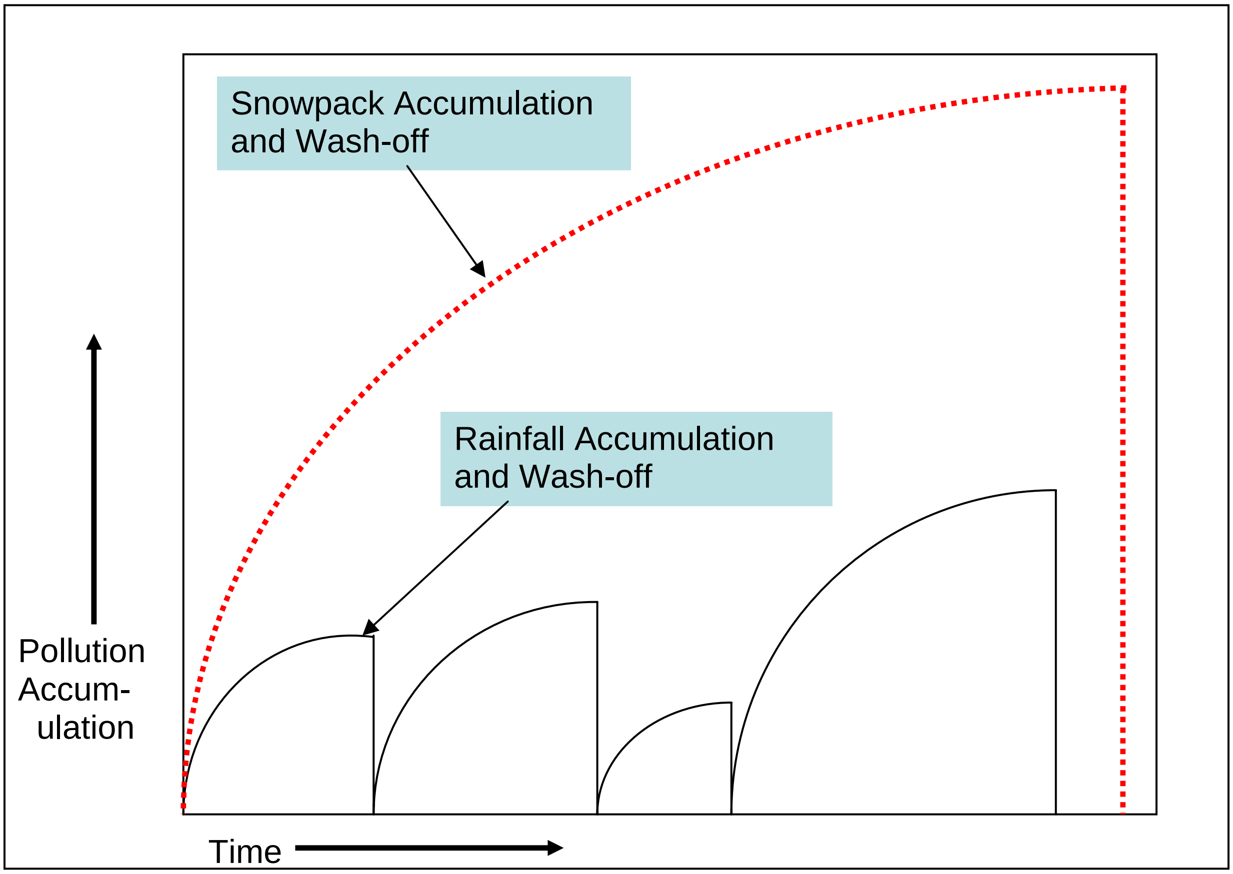
2c. Areas Well Removed from Roadways and High Traffic.

The relative contributions of the three principal areas shown in Figures 2a-c cannot be generalized because of the mix that occurs within any watershed. However, the characteristics of a specific watershed and the management approach needed as a result can be estimated from the mix. That is, a densely developed urban area will have more roadways and impervious parking surfaces typical of Figure 2a, whereas a suburban neighborhood or rural setting will be a larger source of volume as one could imagine from the snowpacks shown in Figure 2c.

A previous MSC Issue Paper on Precipitation Frequency and Use (IP “B”) discussed the manner in which snow builds, increases in moisture content as the winter season draws toward melt, and moves from the snowpack into the ground or over the land surface. A very important part of snowmelt management for both quantity and quality depends upon this behavior and the variations it takes. It is very common for the first part of the melt to soak into the ground, as previously mentioned. However, at some point in the melt sequence, particularly when there is a deep snowpack at the on-set, the ground can become saturated and turn a pervious, non-contributing part of the watershed into an essentially impervious surface from which all additional melt runs off. Hydrographs from melt events will typically show a period of little to no runoff, even though the melt rate might be high, followed by accelerating flow as the ground no longer soaks in the melting snowpack. This process has been described in detail by many authors, including Buttle (1990), and Westerström (1984). The use of this behavior could be important for early runoff and quality management, as discussed in a later section.

Quality of Melt. The water quality problems associated with melt occur because the large volume of water released during melt and rain-on-snow events not only carries with it the material accumulated in the snowpack all winter, but also material it picks up as it flows over the land’s surface. Figure 3 illustrates the accumulation of surface material on a snowpack compared to that occurring on the same urban surface during the rainfall season. The winter accumulation can occur directly on a standing snowpack or on the side of a roadway where it is plowed. In either case, the material builds for several months prior to wash-off. Since snow is a very effective scavenger of atmospheric pollutants, literally any airborne material present in a snow catchment will show up in meltwater when it runs off. Add to this the material applied to, or deposited upon the land surface, for example to melt snow or prevent cars from sliding, and the wide range of potential pollutants becomes apparent. As with the volume of meltwater, a major portion of annual pollutant loading can be associated with spring melt events.

Figure 3. Snowpack Pollution Accumulation and Wash-off as Compared to Rainfall.



Much discussion of the water quality associated with these events and references to many associated pieces of literature occurs in Novotny *et al*. (1999) and UNESCO (2000). Marsalek *et al*. (2003) summarized the state of knowledge in proceedings from an international snow conference in Riksgränsen, Sweden proceedings, which reports on several studies from the U.S., Canada and Sweden.

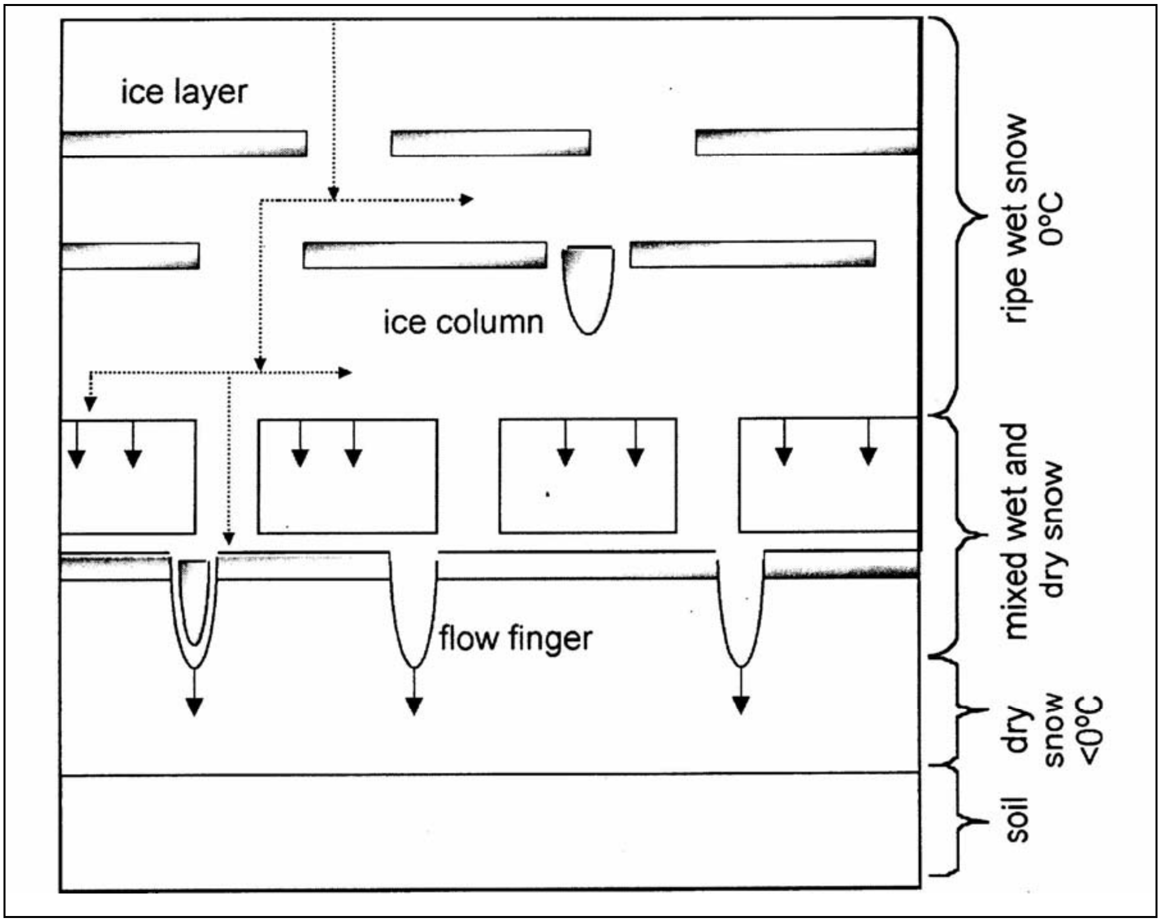
The conventional pollutants of concern for most urban runoff situations are supplemented in meltwater runoff by additional contaminants added during the winter. The solids, nutrients, and metals present during the summer are joined by increased polynuclear aromatic hydrocarbons (PAHs) and hydrocarbons from inefficient and increased fuel combustion; by salt and increased solids from anti-skid application; and by cyanide that has been added as an anti-caking additive to salt. Pesticide and fertilizer runoff and organic debris are less of a concern during the winter. Much of the rest of this Manual focuses on the cold weather contaminants of concern.

The complex melting pattern that occurs within a snowpack results in the release of pollutants at different times during the melt, further complicating an already difficult management scenario. The variability of snow character and the repeated freeze-thaw

cycles that occur throughout a long winter create a very heterogeneous snowpack, with many different flow paths available for melt water to move along (Figure 4). The freeze-thaw cycles also result in the re-crystallization of snow and the subsequent exclusion of "impurities" to the outside edge of the crystals, whereupon they become available for wash-off by the melting front as it passes. This process has been extensively documented in classic works by Colbeck (1978, 1981, 1991), Marsh and Woo (1984), and Jeffries (1988), among others. The process has been called by many different names, including "preferential elution", "freeze extraction" and "first flush". This melting sequence becomes a very important part of approaching snowmelt quality management because the practices we use may or may not come close to treating a particular target pollutant depending upon where in the sequence it is captured.

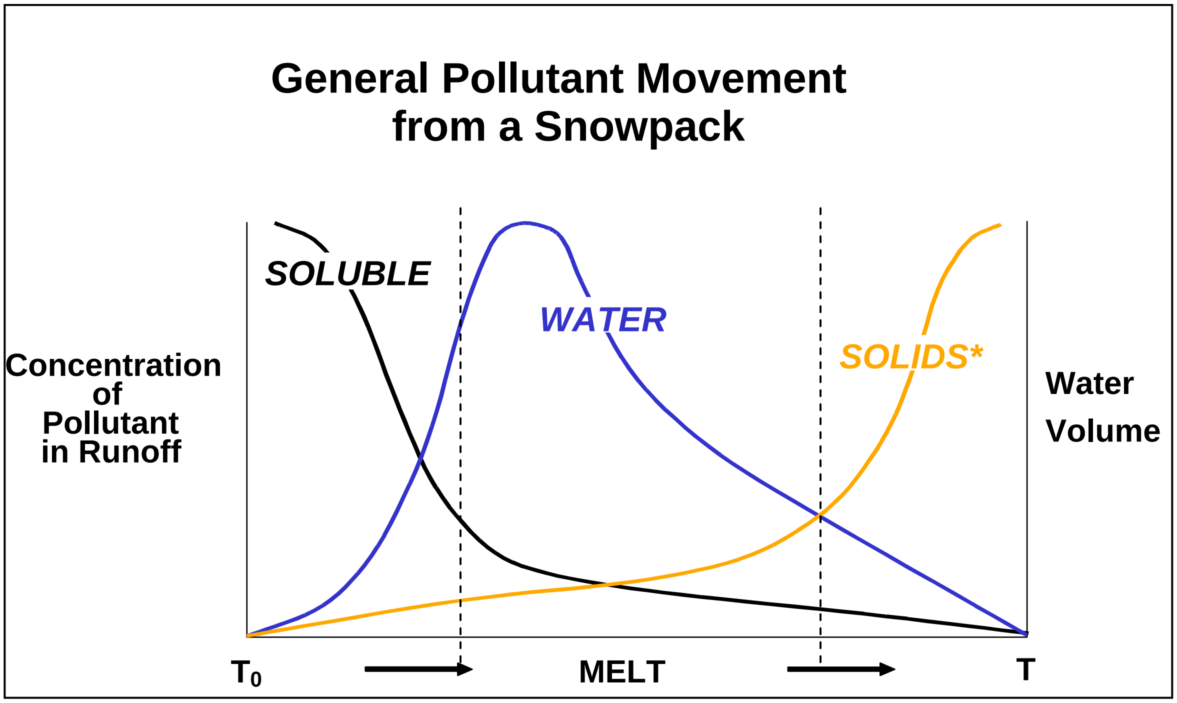
Figure 4 shows how melt water can move downward in a snowpack through different flow-paths around "dry" snow and ice layers caused by repeated freeze-thaw cycles. As this water moves through, it picks up or mobilizes soluble ions that have pushed to the edge of ice crystals. Through this process, the snowpack cleanses itself of soluble contaminants that become available in the first phases of the melt, yielding a highly soluble, acidic and perhaps toxic (to animal and plant-life) runoff volume. Later in the event, melt water from the snowpack is depleted in these soluble contaminants, but water flow can be at its highest. However, energy levels are only high enough to move fine- to medium-grained particulates when the snowpack allows their passage, leaving behind the coarser-grained material. The coarser material will be available for wash-off during the higher energy spring rainfall events, and become a major source of contamination at that time. Alert sweeping can pick this coarse material up from paved surfaces if there is an opportunity between the departure of snow and the first rains.

Figure 4. Percolation of Water Through a Snowpack, from UNESCO 2000 (Chapter 2, Semadeni-Davies and Bengtsson, as adapted from Marsh and Woo, 1984).



The management implication of the preferential elution process is illustrated in Figure 5. The graphic shows that the early part of the melt involves the very efficient elution of soluble constituents (ex., Cl, dissolved metals and nutrients, dissolved organics) at the crystal edges, resulting in a substantial release of the soluble component of a snowpack, often resulting in a "shock" effect as these pollutants reach a receiving water body. Following the release of solubles is a period when much of the liquid volume of the snowpack releases (skewed toward the earlier part of the mid-melt event) and carries with it the remaining solubles along with the beginning portion of finer-grained solids and associated contaminants (ex. hydrophobic PAHs). This mid-melt period generally has the largest portion of water runoff associated with the melt, and the mobilization of solids begins and continues as long as sufficient energy is available to move the finer particles, leaving behind the larger particles.

Figure 5. Generalized melt behavior.



* Note that much of the coarse-grained material remains behind for spring wash-off

Early	Middle	Late
	Character	
High soluble content	Remaining solubles, beginning of fine- to medium-solids,	High solids content
Low runoff volume, early infiltration	Large runoff volume	Large runoff volume (especially if rain-on-snow occurs), saturated soils
Initiated by chemical addition and/or solar radiation	Largely driven by solar radiation, aided by salt	Solar driven
	Land Use Where Important	
Low density	High density	High density
Residential/neighborhood	Roads, parking lots	Roads, highways
Open space	Snow storage sites	Commercial
	BMP Focus	
Infiltration	Pretreatment (settling)	Pretreatment (settling)
Dilution	Volume control	Filtration
Pollution prevention (salt, chemical application)	Detention/settling	Volume control
Retention		Pollution prevention (surface sweeping)
Wetlands/vegetation (infiltration, biological and soil uptake)		Detention/settling
Diffuse runoff paths		Wetlands/vegetation (filtration, settling)

Part of the severity of the water quality problem associated with melt is that it occurs when the hydrologic system is least able to deal with it. Routine assumptions on biological activity, aeration, settling, and pollutant degradation are altered by the cold temperatures, cold water and ice covered conditions that prevail for many months. An end of the season rain-on-snow event often presents the worst-case scenario whereupon rain falls onto a deep, possibly saturated snowpack. The movement of a well defined, rapidly moving wetted front through the snowpack results in the mobilization of soluble constituents, plus the energy associated with the rainfall is sufficient to mobilize the fine-grained or possibly larger solids and associated contaminants. This wave of melt also washes over urban surfaces and picks up material that has been deposited on these surfaces all winter. Comprehensive reviews of the quality of snowmelt are presented in many of the references in Appendix A.

The toxicity of the meltwater and the effects that these chemicals have on various receiving waters and related biological resources is still poorly understood. We understand that meltwater can be extremely concentrated in many different toxic substances (metals, PAHs, organics, free cyanide, chloride). However, we know little about the impact of these substances on streams, lakes, groundwater and wetlands, and even less about their impact on plants, invertebrates, fish and other biological life.

The effects of road salting, especially the conservative element chloride (Cl), becomes increasingly important as the number of vehicles in the state dramatically increases. With the increased number of vehicles comes a need to provide ever safer traffic-ways, which translates into ice-free roads for several months in cold climates. The increase in road salt has even led the Government of Canada to recommend the inclusion of Cl as a toxic substance because of the impact of this chemical on ground and surface waters. Associated with Cl is the anti-caking salt additive, sodium ferrocyanide, which is used commonly in Minnesota. Although not toxic itself, ferrocyanide can break down to free cyanide, which is extremely toxic at low levels. Recent data (Table 1) collected in Minnesota from a group of large salt storage facilities (Minnesota Pollution Control Agency, unpublished data) and limited data from two County public works facilities during 2002-2003 (Oberts - unpublished data) has shown that chemicals associated with salting operations (Na, Cl and cyanide) can reach very high levels in runoff from sites where salt is stored and handled, even if recommended handling procedures are followed. Not much similar data has been collected from roadways to show the effect where the salt is applied, but limited data from the Shingle Creek Mn/DOT Chloride Study does not show any free cyanide.

Table 1. Unpublished Water Quality Data from Minnesota Salt Storage and County Public Works Facilities.

Date (sample type, N=number of samples)	Sodium - mg/L Na	Chloride - mg/L Cl	Free Cyanide - µg/L FCN
1999 (MPCA* sampling of runoff in the vicinity of four large salt storage piles; N = 9)	--	--	120 - 1,500
7/10, 8/9, 8/21 and 11/8/02 (pre-season baseline samples in pond receiving public works facility runoff; N = 5)	14 - 150	19 - 230	ND - <100
11/8/02 (three shallow groundwater samples at public works facilities; N = 3)	71 - 4,210	188 - 7,540	ND
2/2/03 (mid-season melt event, surface water runoff during salting operations at public works facilities; N = 5)	6,260 - 16,700	15,400 - 29,400	ND (2 samples) - 21.0
3/14 and 3/20/03 (rainfall runoff immediately after snow/ice gone from public works facilities; N = 3)	346 - 1,470	530 - 2,200	ND
Water Quality Guidelines and Standards	Non-enforceable “drinking water equivalent level” = 20 mg/L; “benchmark for concern” = 120 mg/L	Non-enforceable “secondary standard” for drinking water = 250 mg/L; chronic water quality standard = 230 mg/L; maximum (acute) water quality standard = 850 mg/L	Enforceable drinking water maximum contaminant level = 200 µg/L; chronic water quality standard = 5.2 µg/L; maximum standard 22 µg/L; final acute value - 45 µg/L

(*K. Cherryholmes, personal communication, 1999)

Groundwater Impact. The previous discussion shows why the most damaging meltwater component affecting groundwater appears to be the two elements associated with the most commonly used road salt - Na and Cl. The damage begins at the soil interface where Na can displace Ca and Mg and disrupt the physical structure of the soil column, and Cl can lower pH and dissociate heavy metals into more soluble and mobile forms. Although both of these chemicals can continue to migrate downward, it is mostly the Cl that presents a major threat. Much more data are needed before we can truly understand the complexity of the Cl threat.

Although the threat is very real and has been documented with groundwater data in many places (summarized well in Marsalek, 2003), in other places even within the same region, the threat is variable. Within the Twin Cities region, for example, groundwater from two watersheds shows some similar and some different results. A groundwater flowpath within the Shingle Creek watershed (Figure 6, Andrews *et al*., 1999) has shown groundwater levels as high as several hundred mg/L Cl, which subsequently discharges as baseflow to the Creek at levels consistently between 20-100 mg/L throughout the year (Figure 7). Surface water runoff Cl content has reached as high as 35,000 mg/L in recent stormsewer inflows to the Creek and similarly reached several thousand mg/L in the Creek itself (preliminary data from the Shingle Creek Watershed Management Commission, 2003). The South Washington Watershed District in the eastern part of the same region of Minnesota has shown groundwater Cl levels (Figure 8) associated with a regional infiltration basin reaching lower peak levels (close to 100 mg/L), but has maintained levels in the same 20-100 mg/L range as Shingle Creek baseflow (groundwater). Site CDP85 shown in Figure 8 collects pumped runoff from a large urbanized basin prior to infiltration, while CDP69 collects localized runoff within a smaller urban area. Chloride levels in the groundwater at both SWWD sites remain within the range of surface water (SW) draining to the facilities. However, the three long-term CDP85 monitoring wells appear to be rising in Cl concentration, although some recent values are certainly within the range of those collected in the early- to mid-1990s. Since the character of the surficial material in the Shingle Creek and SWWD areas is essentially the same, the major difference appears to be in the amount of salt applied to the surface and the routing of salt-laden runoff before it infiltrates. Additional data collection continues on both of these areas within the Twin Cities region. Exploration of factors determining the behavior and accumulation of Cl in groundwater will help shed light on how to avoid contaminating the source that many relay upon for drinking water. The implications for future use of infiltration BMPs is discussed later in the paper (Section III).

Figure 6. Chloride Behavior along an Urban Groundwater Flowpath in Minnesota (July 1997, from Andrews *et al*., 1999).

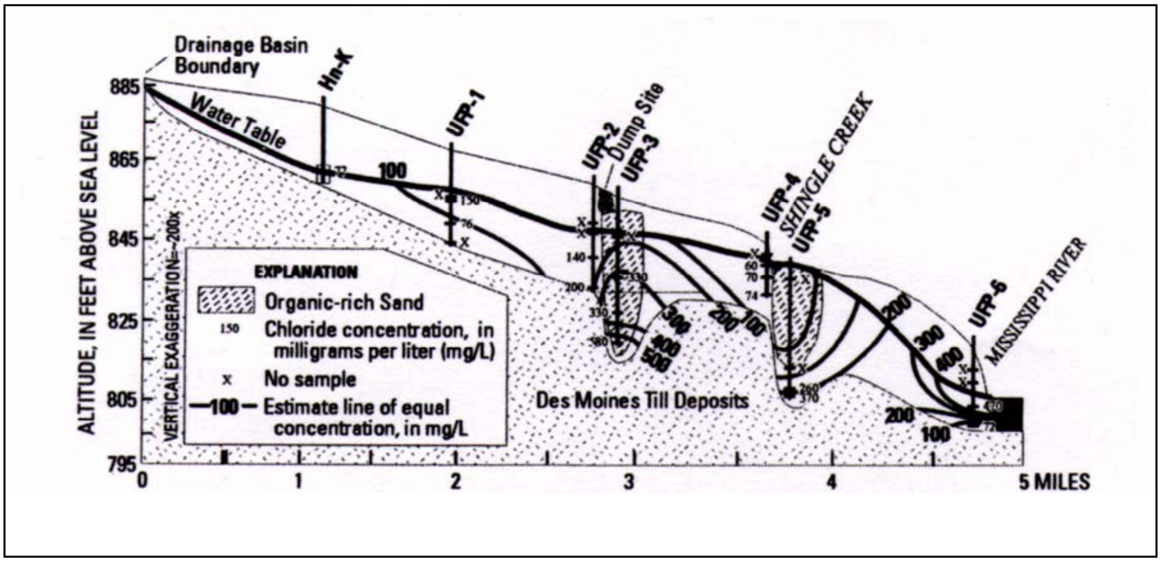


Figure 7. Shingle Creek (surface water) Chloride Data (Shingle Creek Watershed Management Commission data).

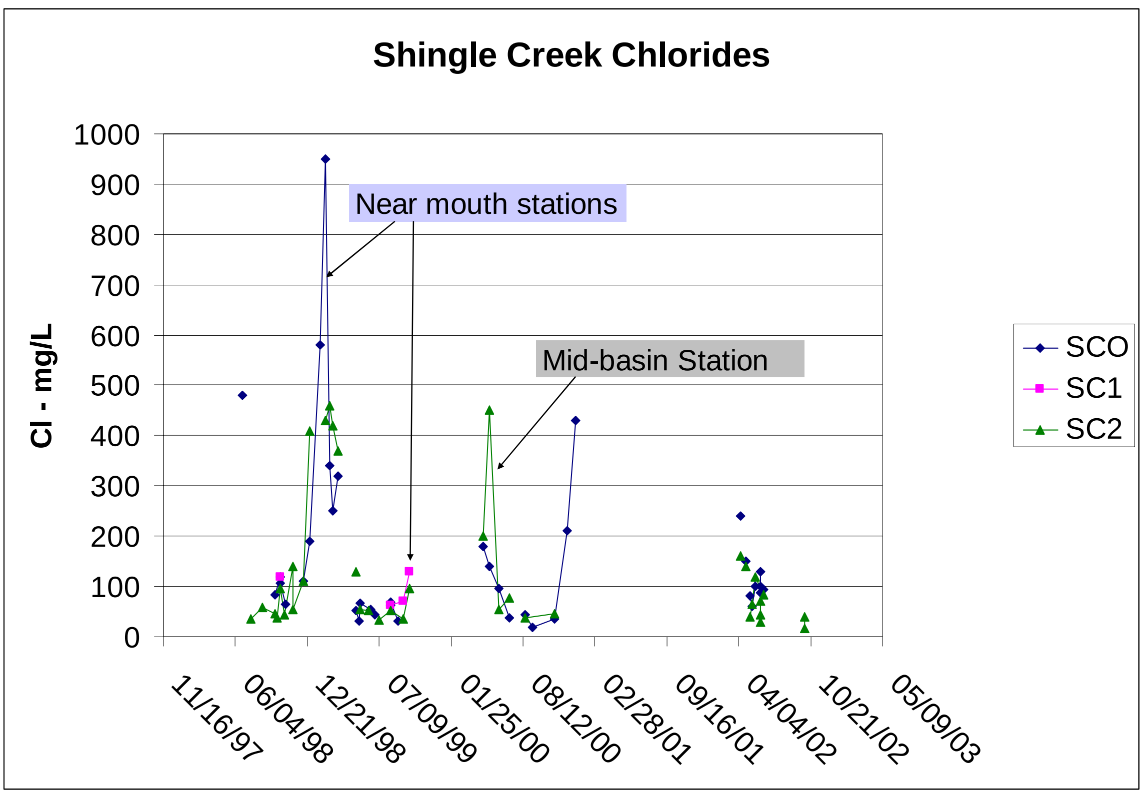
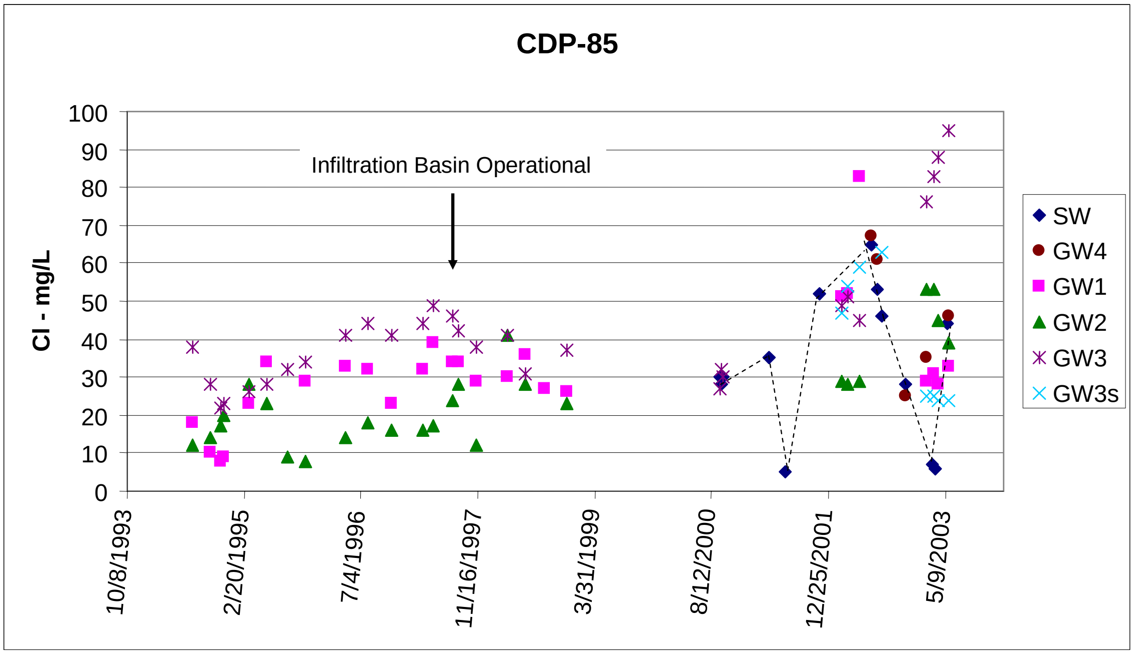
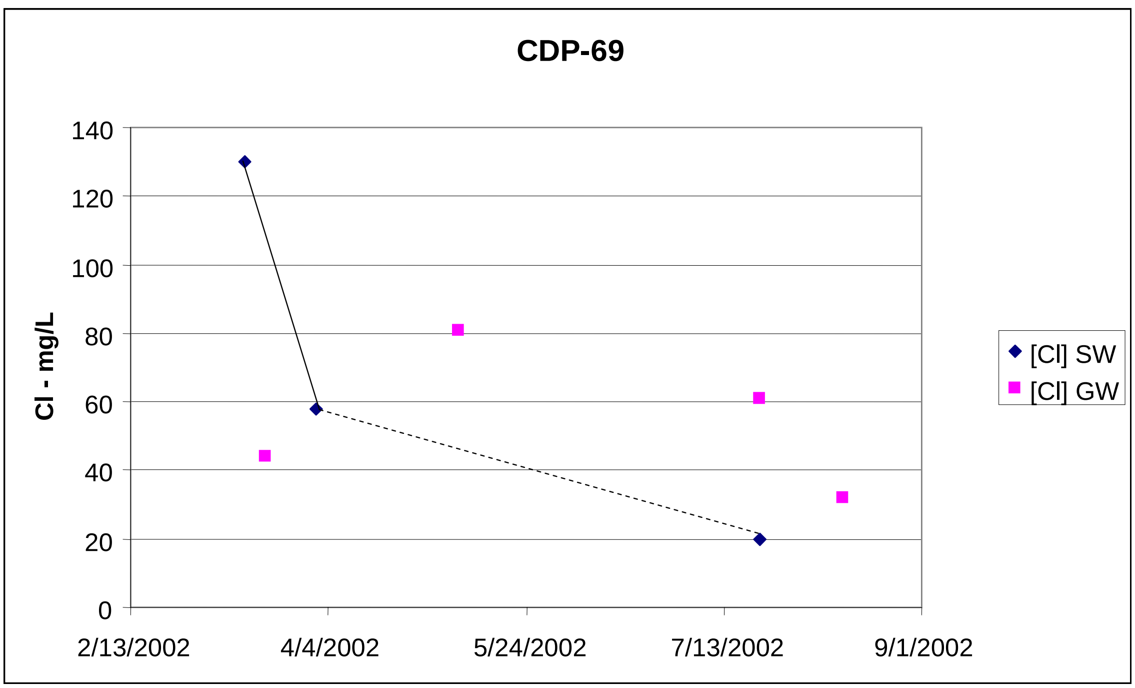


Figure 8. Comparison of Cl in Surface and Ground Water* at Two Infiltration Sites (South Washington Watershed District data).

* Note in Figure 8 that "SW" = surface water site associated with the infiltration basin, and that "GW" denotes a series of groundwater monitoring wells around the infiltration basin at various depths.





Wetland, Open Space and Biological Impacts. There are scant data available on the impact of meltwater on wetland systems and associated open space areas. The classic work by Isabelle *et al*. (1987) defines the potential damage that meltwater presents, but follow-up data collection in other systems and other geographic areas has not occurred to a large extent. This information is critical as we enter a period when the use of “natural systems” for runoff management is increasingly promoted. Is this a wise thing to suggest for meltwater routing, or should these areas be avoided for the portion of the annual cycle involving snowmelt? Marsalek (2003) summarizes the impacts of meltwater runoff on wetlands and receiving water biota. Among these impacts are species shifts to less desirable species, increased toxicity to various biota, and decreased diversity. The final Manual draft will contain an appendix with recommended vegetative species for use in various surface water management approaches. A very good resource on the topic has been produced through MPCA, entitled *Plants for Stormwater Design - Species Selection for the Upper Midwest* (Shaw and Schmidt, 2003).

Effects of Climate Change. The Precipitation Frequency Analysis and Use Issue Paper (“B”) addressed some expected changes in Minnesota that could result from global climate change. The changes noted in that Issue Paper, as well as others collected from the global climate research community indicate that that the following changes are likely:

- Warmer winters
- Higher minimum temperatures
- Greater annual precipitation with:
  - more snowfall, but faster melting and smaller snowpacks
  - more days with rain (possibly when snow present)
- Local weather less predictable and forecast less accurate
- Local weather more variable with longer periods of drought and wetness
- Local weather more severe (more “storms of the century”)
- Stormwater and flood design criteria changes to reflect new conditions more accurately
- Less annual runoff, frequent summer droughts
- Lack of ice cover or thinning of cover, decreased annual freshette (high spring flows), warmer water temps, loss of wetlands, reduced WQ

Regardless of the results of the debate raging on the cause of changing climate, it is clear that we are in a period of global warming. The results of this phenomenon on the character of snow accumulation and melt could be substantial in the long-term. It seems clear that snow will fall in changed patterns and that which falls will accumulate less; that snowfall terminus lines will shift northward, and upward in elevation; that the mix of ice storms and rain-on-snow will increase; that the timing and rate of snowmelt will vary from current conditions; and that the likelihood of flooding events associated with rainfall during spring melt will increase. This is a future that could also imply more chemical use to provide road safety, less chance for effective storage of snowmelt for later use, and altered annual water balances. It is also assured that any scenario for the future will include a substantial amount on uncertainty in both climatic factors and social factors as we implement solutions to perceived and real problems. Clearly, better cold climate data analysis, continued input of data into the development of future scenarios, assessment of

the variability associated with those scenarios and the repercussions for cold climate hydrology and water quality, and identification of possible management changes are all important research needs that must feed into the continuing discussions on the possible effects of climate change. These kinds of evaluations are needed to bring global and national scale modeling into local perspective, and conversely, these data are needed as input to improve the larger-scale models. Any observations or data that Minnesota water managers can document on the behavior of snow accumulation and melt will help reduce this information shortage.

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- Should higher levels of treatment (i.e., pollutant removal) be recommended, perhaps in an SWPPP, based on land use, snow management plans, and anticipated pollutant loads of priority pollutants (sediment, chlorides, nutrients)?
- Should higher levels of treatment be recommended based on receiving water quality or proximity to drinking water source protection areas?

III. KEY CHALLENGES IN ENGINEERING AND DESIGN

List of Complicating Factors for Cold Climate Design

The physical and chemical processes under way in a snowpack present an extremely complicated and variable set of phenomena. The freeze-thaw cycle and the elution of chemicals that it drives have been understood for many years, but details on the migration and management of the many chemicals of concern from the snowpack are seldom pursued by runoff managers. In 1997, the Center for Watershed Protection produced a design manual intended to address many of these problems. One of the tasks reported in that manual was a survey of cold climate stormwater managers asking what the challenges were that they faced. Table 2 below is a reproduction of a table from the CWP report.

Table 2. Challenges to the Design of Runoff Management Practices in Cold Climates (from Caraco and Claytor, 1997).

Climatic Condition	BMP Design Challenge
Cold Temperatures	• Pipe freezing • Permanent pool ice-covered • Reduced biological activity • Reduced oxygen levels during ice cover • Reduced settling velocities
Deep Frost Line	• Frost heaving • Reduced soil infiltration • Pipe freezing
Short Growing Season	• Short time period to establish vegetation • Different plant species appropriate to cold climates than moderate climates
Significant Snowfall	• High runoff volumes during snowmelt and rain-on-snow • High pollutant loads during spring melt • Other impacts of road salt/deicers • Snow management may affect BMP storage

A special session was held at the 2003 Maine cold climate conference during which practitioners were asked the same question. Also, the November 3, 2004 public input meeting for the Minnesota Stormwater Manual held an open "listening" session during which attendees could list problem they face. In both of these cases, the basic problems noted in Table 2 were still identified as those that concern managers. In short, frozen conditions complicate the movement and treatment of meltwater or rain-on-snow runoff. While no magic new practices exist to treat this runoff, some adaptation of our existing approach to design and snow management could be the key to addressing this situation in cold climates.

Management Approaches

Meltwater Management

Special management of cold weather runoff is usually required because of the extended storage of precipitation and pollutants in catchment snowpack, the processes occurring in snowpack, and the changes in the catchment surface and transport network by snow and ice. The discharges that come from urban meltwater may cause physical, chemical, biological and combined effects in receiving waters and thereby limit their quality, ecosystems and beneficial uses (Marsalek *et al.*, 2003).

For many years the old adage "one size fits all" was tried for the management of all runoff management. Once the effects of this approach were scrutinized, however, it became apparent that applying traditional rainfall runoff BMPs was not working for meltwater in spite of their success with rainfall. The problem is usually not the large volume resulting from a significant event, although serious flooding certainly can occur. Rather, it is that the BMPs are prevented from working as intended because of ice, cold water, highly concentrated pollution and lack of biological activity. Complications encountered in cold climates simply work against many of the commonly used warm weather BMPs, reinforcing the need for the development or adaptation (e.g. revised criteria and specifications) of existing treatment practices to better address melt runoff. Additionally, the usually poorer performance exhibited during cold weather is generally not considered when management approaches are designed because of the perceived uselessness in trying to overcome the items in Table 2. The Minnesota Manual gives us the opportunity to suggest ways in which cold weather management can be adapted to deal with these problems. It is certainly agreed that the problems cannot be entirely negated, but any improvement in the quantity and quality of runoff will be a step forward.

Typical results of the conditions listed above include flow by-passing and flooding, lack of reaeration in the water column, pond stratification, decreased settling and biological uptake, flushing of previously settled material, and reduced infiltration capacity. Difficulties associated with management are discussed in detail in Chapter 6 of the UNESCO 2000 report.

Management Sequence

The manner in which meltwater runs off of different contributing surfaces was addressed in a Section II. This behavior suggests that a sequence be followed to intercept and treat variable quantities and qualities of runoff as they emerge. The following general, idealized approach should be used in planning a strategy for optimizing treatment effectiveness when it is possible to implement. Specific BMP adaptations to account for these strategies will be discussed in a later section.

Step 1 - Pollution prevention is always the best way to manage the quality of runoff from urban and rural surfaces. The next section (Pollution Prevention) itemizes several things to consider in the case of meltwater and snow management.

Step 2 - The highly soluble and perhaps toxic "first flush" should be infiltrated to the extent possible provided the source area is <u>not</u> concentrated in Cl or other toxic pollutants. This can be done on-site in areas with a high degree of pervious surfaces, or perhaps routed to an area where short-term detention and infiltration can occur. Local infiltration systems, like bioretention (rain gardens, swales) and dry ponds are a good approach to route water for infiltration or filtration. For source areas high in Cl and soluble toxics or near drinking water sources, infiltration should be avoided in favor of storage and slow release once sufficient flow occurs in the receiving water to dilute the effects. Note also that snow deposits should not be located directly over a designed infiltration facility because of the possibility of clogging from debris in the snow.

Step 3 - Excess flow that cannot be infiltrated because of preventive (frozen) or pollution conditions should be collected in a meltwater storage area with excess capacity to hold it for the later influx of water volume and particulates. These particulates can adsorb solubles and settle, thus removing a portion of the more toxic soluble load. To accomplish this, a "seasonal" approach to storage capacity adjustments will be needed (see Ponds section that follows).

Step 4 - When fine- and medium-grained solids begin to move, settling BMPs can be incorporated starting with local application, and moving to regional storage as the need dictates. Again, some adaptations will be needed to incorporate storage around the ice layers that might be present.

*Step 5** - Much of the remaining solids are too heavy to be moved by melt so they remain near the roadside, in gutters, or in the location they were dumped as part of a snow pile. Because these heavy materials do not usually move with snowmelt, they are available for wash-off when spring rains come with sufficient energy to move them. After the snowpack has totally melted and before the first rainfall (if possible) preventive measures such as street and parking lot sweeping should be pursued. This is also a time when snow dumps should be maintained. This approach will manage a substantial portion of solids associated with melt conditions.

*Note that Step 5 could occur after Step 1 for those communities or commercial/industrial facilities that practice cleaning activities during the winter.

The sequence above, of course, is an optimal approach and ideal conditions seldom occur. Some cautions to keep in mind while managing this approach are discussed in the following sections.

<u>ISSUE #2:</u> Should the above sequence of management steps be suggested in the Manual as a logical progression of steps toward meltwater runoff management?

Pollution Prevention

Keeping contaminating materials away from paved surface and out of accumulated or dumped snow is the key to minimizing the pollution associated with meltwater runoff. Management approaches that help accomplish this include:

- Judicious use of de-icing and anti-skid chemicals, which then indirectly control secondary effects like heavy metal speciation and soil character changes from Cl
- Less additives like cyanide (CN) to salt
- Better chemical storage and mixing (covered storage and mix areas, mix only needed amount)
- Improved application technology with trucks, such as weather monitoring (RWIS or "road weather information systems"), direct application to roadway, and brine wetting
- Snow removal and meltwater routing to less sensitive receiving waters or treatment facilities
- Design of Cl dilution system to lower its direct impact
- Rapid sweeping as soon as snow gone from pave surfaces
- Litter control
- Erosion control
- Disconnection of impervious surfaces/reduced pavement (such as narrow roads, fewer parking spaces)

As discussed in Section II, Cl is the cause of many problems associated with snowmelt runoff. Chloride is a very soluble, conservative chemical that migrates easily through treatment systems and soil. High Cl levels decrease sorption of heavy metals and mobilize them. This leads to release of these polluting materials from storage areas with high Cl levels, as density stratification leads to the build-up of Cl to very high levels if not properly flushed from bottom waters. Methods to prevent this are discussed in the ponding section.

Infiltration

As indicated in Step 2 above, after some basic pollution prevention is practiced, the next phase of runoff management should be to soak in as much of the meltwater as possible, provided the source area does not contribute high Cl or soluble toxic pollutants. The treatment available from infiltrating meltwater through soil (filtration, ion exchange, adsorption, and biological decomposition/transformation) will remove many of the most polluting contaminants typical of low density urban areas. These practices are, therefore, most appropriate for residential and open space areas within a watershed.

Section II described the problems that Cl-laden runoff can cause in both surface water and groundwater. However, in addition to Cl, early runoff can include other soluble pollutants. The degree to which soluble contaminants will be pervasive is a function of the source load and the amount of particulates available to possibly adsorb them. Sansalone and Buchberger (1996) found that when a high level of particulate material is

present in meltwater that a fair amount of adsorption occurs, negating some of the mobilization of this otherwise potentially toxic material. For source areas where runoff is a possibility, routing the runoff to a facility where an opportunity exists for this sorption to take place is a management option. Similarly, some sorption from these areas might naturally occur, so routing to a storage facility is again advisable for settling of the particulates and adsorbed material.

Although infiltration has not been a commonly used meltwater BMP in Minnesota, studies from many similar climates (as reported in Issue Paper "B" and in research from Bäckström's series in Sweden, William James and R.J. Granger *et al.* in Canada, and Cahill Associates in the eastern U.S.) show that it is a feasible practice when used with precautions. Specific BMPs that involve infiltration include such practices as trenches and basins, permeable pavement and paving blocks, vegetated swales and biofilters.

The following base criteria for infiltration BMPs are adapted from the CWP cold climate design supplement (Caraco and Claytor, 1997: Table 5.2) and supplemented by additional criteria:

- Underlying soils should have an infiltration rate of >0.5 inches per hour or 1.5-2.0 inches per hour for facilities draining more than 10 acres;
- Soils should have a clay content of less than 30% and a silt/clay content less than 40%;
- The minimum rate of infiltration should match as closely as possible the local rate prior to development;
- Infiltration facilities should not be located on even moderately (~12-15%) steep slopes;
- "Hotspot" or high pollution areas (such as gas stations, chemical storage facilities) should never drain to an infiltration system;
- The bottom of the infiltration system should be at least three feet from the water table or seasonally saturated soils;
- Any infiltration facility should be at least 100 feet from any well used for drinking water supply;
- Full dewatering of any infiltration facility should occur within 48 hours;
- Pre-treatment (settling and/or filtering) must occur prior to inflow and an emergency plan developed in the event of contaminant spillage near or into the system;
- If possible, the system should be dried out in the fall prior to frost formation;
- Systems should be installed after site construction has ceased to prevent clogging with sediment;
- An evaluation of local groundwater conditions, including the presence of karst geology, should be done;
- A maintenance plan should be developed and implementation mandated as part of any installation;
- A groundwater mounding analysis should be done to see if mounding is possible and if so, would it present a problem; and

- Specifically designed infiltration facilities should not be used for snow storage because of the possibility of clogging from the debris and sediment within the snow.

Routing meltwater into or away from an infiltration system is also an active meltwater management decision that can be made depending upon conditions. For example, highly Cl-laden water can be routed away from an infiltration system that might operate during three seasons, but not the winter. On the other hand, meltwater from a residential area could be routed to an infiltration system to take advantage of early melt infiltration into a dry infiltration basin.

Adaptations for improved operation of infiltration facilities in cold weather are discussed in Section V.

> **ISSUE #3:** Both of the previous Issue Papers ("A" and "B") recognized infiltration based BMPs as desirable for Minnesota. The potential introduction of Cl and the possible loss of effective performance during cold weather means that infiltration-based systems should be used carefully as a winter practice.
> - Should they continue to be promoted, but with very clear cautions and restrictions, such as sizing for a larger design event to capture and treat during melt?
> - Should a more prescriptive treatment train be recommended for infiltration practices, such as oversized pretreatment, possible use of proprietary sediment removal, or further down-gradient treatment if needed for by-pass?

Ponds

The most commonly used rainfall runoff BMP has been various versions of detention ponding. Difficulties in applying warm weather detention concepts to cold weather meltwater treatment occur with higher runoff volumes and increased pollutant loads, ice layers and frozen/sand-plugged conduits, anaerobic conditions, greatly enriched under-ice accumulation of pollutants, circulation problems and resuspension.

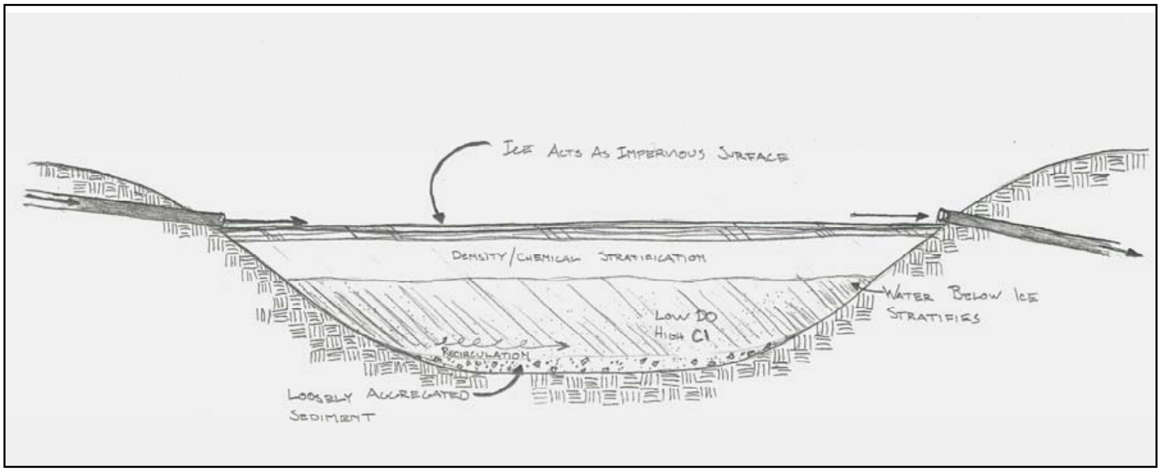
Although much discussion and speculation on the performance of detention ponds during meltwater movement has occurred, the only fully equipped under-ice study of such a pond was done in Kingston, Ontario by Marsalek *et al*. (2000). Among the findings for this pond were:

- Densimetric stratification caused by accumulation of road salt in runoff;
- Anaerobic conditions evolving once ice prevented reaeration and baseflow ceased;
- Release of pollutants, once thought to be permanently removed, from both bottom sediment and interstitial waters; and

- Displacement and flushing of highly polluted under-ice pond water with the first waves of meltwater that sink below the ice layer in ice-free areas near the inflow.

Figure 9 graphically summarizes the many processes that work to limit the effectiveness of ponding during meltwater events.

Figure 9. Character of Water Under Ice.



Understanding better the dynamics of sedimentation and resuspension will be necessary to building better cold climate detention systems in the future, and to retro-fitting the thousands in place already in Minnesota. Data collection on some of the meltwater treatment adaptations, such as seasonal detention, variable outlets, under-ice circulation, and first melt diversion into or around a treatment system, is greatly needed if we are to ever identify BMPs that are effective for both meltwater and rainfall runoff treatment.

In spite of the fact that detention systems often do not work well under typical designs in cold weather, they play a prominent role in treatment of meltwater. In the areas draining the paved areas and those areas accumulating snow and ice near paved areas, particulate content can become extremely high because of a winter's accumulation of anti-skid sand and urban debris. Routing this runoff to a detention facility prior to release to a receiving water is a reasonable thing to do. This large mass of particulates near these surfaces also plays an important role in adsorbing soluble pollutants that otherwise might escape further treatment (Sansalone and Buchberger, 1996). For both of these reasons, an adapted ponding system is among the list of recommended treatment methods for meltwater management.

Ponds also provide an opportunity to store, mix and slowly release pollutants mobilized during a melt event. Oftentimes, pollutants like Cl in meltwater can rise to toxic levels. If routed into a storage facility and slowly released when sufficient water is, for example, flowing in a receiving stream, the toxic effects can be minimized. Ponds can also be used

to accumulate all or a substantial part of the meltwater volume for later release when biological and physical constraints are less apparent.

It is important to recognize the potential pollution problems that Cl and toxic contaminant build-up in a pond can cause when released. A delicate balance needs to be pursued in deciding whether to adjust pond level to pass Cl-laden runoff downstream or retain as much as possible for later release when flows are higher. Retaining polluted water all winter long only to discharge it all at once in the spring is not in the best interest of receiving waters, but this is what can happen in a pond not managed for seasonally changing conditions. In no case should ponds be drained in the spring following a winter's long accumulation of under-ice contaminants. If lowering is done, it should be done in the late fall before freeze-up.

Adaptations to commonly designed ponding systems are discussed in Section V. They generally consist of altering water levels and promoting low velocity circulation. Monitoring of the quality of water in a pond under the ice would help to determine if extreme water quality problems are likely to occur as water is flushed out from beneath the ice as the first waves of meltwater move through the pond.

The base criteria for ponding will be addressed in the design sheets prepared for various ponding BMPs once the unified sizing criteria discussion occurs with the MSC. The many variations that could be part of pond sizing will be sorted and applied as design recommendations in the detailed sheets produced for the Manual.

> **ISSUE #4:** Should the unified sizing criteria for ponding (if and when adopted) include adaptations that would account for less effective cold weather treatment or should we view any improvement through adaptation as an extra benefit outside of the criteria?

Wetland and Biological-Based

In Minnesota, wetlands often act as modified detention facilities by virtue of their sheer numbers and the location they occupy in the drainage landscape. Most of the constraints listed above for ponds also apply to the proper operation of wetland treatment systems. In addition, however, is the sparse biological activity during the cold weather season. Vegetative uptake, filtering and microbial activity are all effective mechanisms to reduce pollution related to biological activity during warm weather that are much reduced when the weather is cold. Although sedimentation might continue to play a role in meltwater treatment, provided an ice layer does not prevent it, decomposition, chemical adsorption and biological transformation will all likely be reduced.

Section II discussed the impacts of Cl-laden meltwater on vegetation. Greatly reduced germination and growth of seeds, reduced community biomass, taxa and productivity, and a shift to less desirable species are all the effect of pollution loading to wetlands.

Other biological systems that are commonly used for rainfall runoff also suffer a drop in effectiveness in winter weather. For example, water draining to vegetated swales and bioretention (rain gardens) systems experience a drop in water quality because of reduced pollution removal.

Even though the pollutant removal effectiveness of biological systems is less during cold weather, these systems certainly have their place in an overall runoff management program. Low-lying wetlands and bioretention areas are the first place that soluble-laden first meltwater will migrate and soak into the ground. Standing vegetation, although not green and vibrant, still provides a measure of filtration as meltwater flows through. Soil microbes still live and consume nutrients even in the dead of winter. Accumulation of Cl is generally not a problem in shallow biological systems, as long as very highly concentrated levels are not routed directly to them. Even when this does occur, salt tolerant vegetation can survive. The best salt tolerant plant species for use in Minnesota will be contained in a Manual appendix.

Filtration, Hydrodynamic Structures and Treatment Trains

Filtration was to some degree addressed in the previous section on wetlands. The aspect of filtration that was not addressed was its role as part of a treatment train, or sequence of treatment steps designed to remove incrementally greater pollution as runoff water flows through. Filtration through a granular inorganic (sand, perlite) or organic (compost, leaf pellet) medium can be a fairly effective way to treat many of the pollutants associated with meltwater. The organic materials are less attractive in Minnesota because of the potential for phosphorus leaching into our lake dominated receiving waters.

Filtration is usually one of the last stages of a treatment train, typically preceded by processes such as screening, settling, floatable skimming, aeration, and chemical addition. Filtration is usually the final process before system infiltration or discharge to an outflow pipe connected to a storm sewer.

These systems can be particularly effective when placed as a sub-grade unit below the frostline. Sub-grade construction also allows for surface land to be used for other things, such as parking or open space.

Many new proprietary management systems are on the market today with promises of year-round effectiveness. Many of these proprietary systems are promising, yet most are untested in cold climates. Perhaps the most promising practices for meltwater are the treatment trains that incorporate settling, floatables skimming, and filtration through some kind of organic or synthetic media. Theoretically, these systems should be able to settle the solids associated with anti-skid grit added over the winter, then remove a fair portion of the soluble toxics also washing off in a melt. Unfortunately, conservative elements like Cl will move through these systems unchanged. The Environmental Technology Verification (ETV) program of USEPA has begun to test the claims of many proprietary units. Available results from this program will be incorporated into BMP

design sheets in the Manual, especially if field data on cold weather performance have been part of the testing procedure on the effectiveness of these systems.

Other Considerations

Alternatives to Sodium Chloride (NaCl)

Perhaps the most vexing problem facing cold climate water managers today in many parts of the world is the accumulation of Cl from the ever-increasing application of road salt (see previous discussions). As a conservative element, Cl moves readily through all commonly used treatment devices and into both ground and surface waters. The only effective means to remove Cl is through reverse osmosis, which does not lend itself to the large volume of runoff associated with a melt runoff event. Other treatments, like evaporation, do not work well during critical cold periods and only serve to concentrate the pollutant for later attention. The treatment approaches that seem to have some likelihood of success are less use (logical, but not in favor by many transportation managers), dilution (mix high load runoff with low load runoff) or detention and slow release to avoid toxic shock. Alternative chemicals have shown some promise in the past, but each alternative seems to bring associated impacts once scrutinized. However, the search for, and evaluation of alternative chemicals or artificial substances for de-icing or anti-icing must continue if we ever hope to reduce our reliance on NaCl. "Smart salting" is the pre-emptive application of deicer to prevent ice from forming. In Minnesota, the use of liquid $MgCl_2$ spray on bridge decks has proven to be an effective way to avoid repeated NaCl application at high doses. Continued data collection on the presence of Cl in receiving waters is essential to the development of a reasonably protective Cl strategy. Other routinely mentioned alternatives to NaCl use are calcium chloride ($CaCl_2$), calcium magnesium acetate (CMA), potassium formate (KFo), potassium acetate (KAc) and urea (used almost exclusively at airports). Until such time as these alternative sources are shown to be effective in controlling ice, environmentally suitable and economically affordable, NaCl will continue to be the chemical of choice by those responsible for keeping roads safe.

> **ISSUE #5:** Should Minnesota be doing more to explore alternatives to the use of NaCl and ways to lower the impact of salt on our receiving waters?

Winter Construction Season

A recent trend in Minnesota as the winters have seemed to be more mild and construction techniques improve is to continue or even initiate building during the winter. Going into a winter building season means all too often that soil and slopes are left bare all winter and exposed to snowmelt and early spring rainfall events with little protection in place.

Under the Phase II NPDES permit provisions, a Storm Water Pollution Prevention Program (SWPPP) must be produced for each construction site over one acre, but often

the provisions of the SWPPP and local ordinances are ignored during the winter because of the infeasibility, for example, of getting vegetation started or of placing material over a frozen surface and having it blow away. A small amount of planning before cold conditions set in could prevent the serious erosion and pollution problems associated with these sites in the spring.

Following is a list of practices and options to consider before the cold weather construction season. Many of these elements are currently required as part of the NPDES Construction Permit, but unfortunately are often overlooked or considered infeasible during cold weather. Effective implementation of all permit requirements during cold weather is important.

- Terminate activity until warm weather returns, if construction not required over winter;
- Sequence work such that all earth-moving and soil impacting activities occur prior to freeze-up;
- Stabilize all exposed soil surfaces with vegetation, mulch or synthetic cover before the ground surface freezes and sprays become inoperable;
- Seed before October 1st to assure germination and adequate growth before cold conditions prevent growth;
- Establish stable access/egress points and stockpiling some gravel on site to maintain these routes during the winter season;
- Install roads to keep all vehicles off of exposed soil;
- Open limited new soil exposures (if any at all) and stabilize them immediately;
- Establish perimeter controls and inspect them weekly throughout the winter for structural integrity (use surface bags or rolls when posts and staples cannot be driven into the ground); and
- Maintain a stockpile of sandbags and other erosion and sedimentation controls (ex. rock bags, erosion blankets) to address problems that need immediate attention.

ISSUE #6: How should the Manual interact with the Phase II program to better address winter construction practices? Should the Manual contain specific guidance on winter construction practices that would minimize water quality degradation?

Snow Management

The plowing, relocation and collection of snow presents some very real management questions in need of support data. In most urban areas, a number of approaches are followed depending upon the level of urban density. In residential areas, snow is generally plowed to the side of the road and allowed to accumulate there all winter long. However, in commercial/industrial zones, snow is often plowed to a corner of a parking lot, and in densely-developed urban centers, snow is often removed to a totally different, often remote area, where it is dumped for an entire winter season. The pros and cons of these different approaches were described in several presentations at Riksgränsen (2003),

yet local practices seem to vary considerably based on tradition, expectations and the cost of removal operations. Assuming snow is collected, the design of "snow dumps" must take into account the fact that snow eventually melts and will need somewhere to flow, either off of the land surface or into the ground. Some suggestions for design were proposed by Wheaton and Rice (2003) based on the Anchorage, Alaska experience, but much more data are needed to build a good suite of sampled designs. Of particular need is data on the impact of these facilities on both ground and surface waters. Until adequate data are available, commonly accepted snow dump practices include:

- Locate on a flat slope well away from surface water bodies, outside of the floodplain and well above the groundwater table;
- Place the collected snow over well-drained soil to allow filtration, adsorption and microbial activity;
- Clean-up of debris left after the snow melts away and before the first spring rains fall, and restore the soil if needed; and
- Monitor the quality of snowmelt and of the receiving water, especially if it is the local groundwater system.

Wheaton and Rice (2003) document the Anchorage, Alaska snow collection and treatment system that uses an impermeable pad under the snow dump, followed by routing collected meltwater to a treatment system. Although this approach was dictated largely by the permanently frozen soils in the area, the idea of collecting potentially contaminating snow dump meltwater is attractive if a sensitive receiving water is at stake.

ISSUE #7: Should Minnesota develop guidelines for the proper operation of snow dump sites?

Low Impact Development

The movement in runoff management toward less structural, "low impact" development techniques shows a great deal of promise. The effectiveness of this approach to runoff management relies to a great extent on the biological and soil systems within a watershed. The ability of these systems to operate in an acceptable manner could mean they are propelled to common practice or doomed to failure. Much of the discussion in Section II above stresses the role that low impact approaches can have in meltwater management. More data on infiltration of meltwater in pervious parts of a watershed would yield valuable insights into how use of alternative or natural treatment systems could be used to better manage cold climate runoff from the entire year.

Much of the world's research on this topic is being done in Norway and Sweden. For example, Magnus Bäckström of Luleå Municipality in Sweden has put together a number of papers (1999 and 2002) documenting his research on grass swales and infiltration systems that work successfully in northern Sweden. Many of these results will be used in the Minnesota Manual when potential effectiveness is entered into the BMP design sheets. Bäckström found that porous pavement has the potential to reduce meltwater

runoff, avoid excessive water on the surface and accomplish groundwater recharge by local infiltration. He also studied grass swales and road drainage infiltration systems under cold climate conditions and found them equally as successful.

Low impact techniques cannot be installed and forgotten about. As with structural runoff systems, low impact approaches require careful maintenance to assure their effective performance.

> **ISSUE #8:** Should low impact development techniques be promoted in the Minnesota Stormwater Manual as a viable meltwater (in addition to rainfall runoff) management approach?

New Research

The field of snowmelt research has not received as much attention this decade as it did in the period from 1975-2000. There have been some very important conferences and collections of existing knowledge, but large-scale research has slowed. Exceptions to this are the Canadian SWAMP Program, US EPA's Environmental Technology Verification (ETV) Program and various academic and government programs in Scandinavia. Even in these efforts, with the exception of the Scandinavian programs, meltwater has not been a focus.

The joint Stormwater Assessment Monitoring and Performance (SWAMP) Program of the Toronto and Region Conservation Authority, Ontario Ministry of Environment and Energy (OMEE), and Municipal Engineer's Association conducts in-depth research on numerous BMP installations to see how they operate from a water quantity and quality standpoint. The OMEE also supports snowmelt runoff and treatment research. Much of the information from these studies will be incorporated into the BMP design sheets created for the Minnesota Manual.

EPA's ETV program was established in 1995 by EPA to test the performance claims made by manufacturers of various environmental technologies, including runoff treatment systems. Participation in the program by producers is voluntary. Some of the runoff treatment systems are currently undergoing performance testing in cold climates. The results of the ETV tests will be used in the BMP effectiveness section of the Minnesota Manual.

Finally, various research universities in Scandinavia continue with a tradition of good snow and meltwater research. Among the many universities conducting this research are Luleå University of Technology (Sweden), the Norwegian University of Science and Technology, Lund University (Sweden) and the University of Kalmar (Sweden). Governmental programs in Scandinavia also support many good studies of cold climate water research.

Decision support for the selection, effectiveness assessment, and operation and maintenance (O&M) of BMPs is needed by practitioners in cold climates. This is part of the reason for production of the Minnesota Manual. Getting user-friendly information into the hands of those managing this runoff is essential. The information most requested by these managers seems to be data on the expected performance for specific practices. This is especially critical in light of the need to meet regulatory requirements for pollutant removal at a specified level. New applications, such as the application of image processing and neural networks (Matheussen and Thorolfsson, 2003) to map and follow the progression of snowfall through melt, show tremendous promise as our computer and imaging technologies improve.

Planning and Education.

All of the design and evaluation assistance that will be contained in the Minnesota Manual will be meaningless if the results do not get properly interpreted and distributed, both to the local officials making decisions and to the public that must live with those decisions. For example, a public clamoring for ice-free roads is in direct conflict with a reduced salt strategy. Local officials also need data and technical assistance to make good decisions on meltwater management. The Minnesota Stormwater Manual is intended to fulfill at least some of this need. Preparation of more of this kind of "on-the-ground" technical information in the hands of everyday managers is essential if we ever hope to improve water management in cold climate areas.

Future Management in Minnesota

The preparation of this Manual provides an excellent opportunity for discussion of both past revelations and exciting new findings. It is the hope of the consulting team that many results will come from these discussions. Success will be achieved if in the next decade we can see progress toward:

- Better data and analytical tools in the hands of all interested users;
- A substantial database on the performance of a whole new suite of meltwater treatment practices;
- An understanding of what will happen to our climate as the world's climate continues to change;
- Full knowledge of the fate of chloride and toxic material carried in meltwater and development of management systems that mitigate those effects; and
- An understanding of the biological repercussions of routing snowmelt into biological systems.

> **ISSUE #9 -** Do we know enough about the behavior of snow and meltwater to adequately design and operate runoff management systems adapted specifically for cold climate use? Is standard BMP technology sufficient to accomplish this task? Should the Manual be a vehicle to get guidance out to users on how BMP adaptations can be made to achieve water quality improvements during snowmelt events?

IV. COLD CLIMATE CONSIDERATIONS IN MINNESOTA STORMWATER MANUAL

Background

To date, the MSC has contemplated cold climate considerations as part of the Precipitation Paper (water quality sizing for snowmelt) and as part of this Cold Climate paper (pollutants in snowmelt, pollutant removal in BMPs, etc.). It is intended that this information will become incorporated into the Minnesota Stormwater Manual, not as a separate topic for stormwater managers and designers, but as an integral part of an effective program/practice for Minnesota. In future papers, the MSC will be considering such questions as:

- ✓ Should a unified sizing criteria/system for Minnesota include sizing recommendations for snowmelt?
- ✓ If a system of water quality credits is recommended for Minnesota, then should it incorporate credits for winter snow management techniques that reduce the need for deicing chemicals?
- ✓ Should water quality credits also be given for site design elements that preserve natural infiltration and discourage connected impervious surfaces?
- ✓ Should snowmelt in sensitive watersheds be managed to a greater standard than non-sensitive watersheds?
- ✓ What BMP design modifications should be recommended for snowmelt and other cold climate considerations?

The Precipitation Frequency and Use Issue Paper ("B") raised the question of how design criteria can be recommended/required such that everyone uses the same approach. Part of the material presented in the paper addressed the inclusion of snowmelt runoff into the calculations. A methodology for determining the snowmelt volume to add into the runoff calculations was suggested as input independent of whatever method is used for defining "water quality volume".

The question that remains was stated also in the Section III discussion of ponds as:

> **ISSUE #4 (re-statement):** Should the unified sizing criteria for ponding (if and when adopted) include adaptations that would account for less effective cold weather treatment or should we view any improvement through adaptation as an extra benefit outside of the criteria?

We must also further consider this runoff in other BMPs besides ponding and the use of any kind of credit for including meltwater design. Although complete answers to all of these questions cannot be determined until the MSC discusses the unified criteria and credits Issue Papers, some additional background on the topic can be presented here.

Water Quality Sizing of Snowmelt

The Precipitation Paper introduced Minnesota climatology data and the common rule of thumb that most of the snowpack disappears in the spring over a period of about ten days. One question that arose at the MSC meeting was why this volume should be important if BMP facilities are generally designed for treating a runoff event lasting only 24-hours. That is, aren't we merely dealing with on average $1/10^{th}$ of a snowmelt runoff volume going into a facility designed to treat a much larger volume? This is a very valid comment.

In the example exercise on page 13 of the Precipitation Paper, a volume of snowmelt runoff was determined to be 3.7 acre-feet. It was compared to a range of rainfall runoff storage needs of 1.5 - 6.4 acre-feet, all generally determined for a daily event. Dividing the snowmelt volume into ten daily increments (on average) yields a design need for only 0.37 acre-feet per day if it is assumed that the system will adequately treat and de-water on a daily basis. Clearly, if the systems built to store 1.5 - 6.4 acre-feet have that much storage available, there will be no problem. The difficulty arises when the complicating factors listed in Table 2 prevent the full storage volume for a pond, or infiltration capacity of an infiltration device, or conveyance for a diversion to be available during the period of time when they are designed to reduce the water quality impacts of runoff. Suddenly the total 3.7 acre-feet of snowmelt could receive less than adequate treatment or by-pass any treatment whatsoever.

Various methods to deal with the conditions experienced in cold climate BMPs were suggested in Section III. But the question raised in Issue #4 remains - do we want to make the adaptations or sizing changes part of the recommended criteria or simply recognize that we might need to change our approach to get the same treatment as the facility was intended to achieve during warm weather? Should we instead think in terms of the entire snowmelt volume over ten days and compare it with the daily value used for warm weather runoff events because we know that the treatment levels will not be the same?

Water Quality Credits for Onsite Snow Management

Depending on positions taken on the above, it may be possible to offer credits. For example, if there is an approved and enforceable snow management plan for a fully developed urban commercial site that dictates plowed snow will be hauled to a suitable on-site snow storage area (e.g., pervious soils, sump area sized to certain design specifications, spring clean-up plan), then the stormwater BMPs can be sized according to the baseline (rainfall runoff) criteria. However, if the same site merely plows the snow to a corner of a parking lot and lets it enter a storm sewer that empties to a nearby pond with a thick ice cover, then maybe the applicable SWPPP needs more attention (mandated or recommended?).

Another opportunity to incorporate credits could be possible if we presumed that the snowmelt sizing approach presented in IP “B” showed that the snowmelt WQv (“water quality volume”, no matter how it is defined later) is greater than the rainfall runoff WQv. If this is the case, certain measures could lead to a reduction in that volume to the point where it approached or equaled the rainfall WQv. Credits such as considering subtracting out roof areas that drain to pervious surfaces could be applied to adjust the snowmelt volumes. If chloride loads are of particular concern, a credit could be given for residential streets that have a “reduced salt” covenant. The street area could be subtracted out of the snowmelt WQv computation.

Perhaps the level of inclusion of a snow management plan should be a function of whether a community is covered under an NPDES MS4 permit. That is, are there exemptions that should be considered such as waiving snowmelt criteria for sites outside of MS4 jurisdictions? Another example might involve waiving snowmelt criteria for direct discharges to streams where ratio of site drainage area to upstream drainage areas is less than some fraction (e.g., 5%). This argument would be loosely founded on the dilution principle, which has been previously identified as one of the limited management approaches for Cl, but might not send a positive message (that is, using dilution to solve a water quality problem).

BMP Design Modifications

Another option originally proposed in the CWP Cold Climate BMP Supplement (Caraco and Claytor, 1997) is to incorporate additional storage or treatment volume into typical designs. The CWP proposed the addition of an extra 25% Extended Detention (ED) storage to ponds for winter use. This approach could also be accommodated under the seasonal designs presented in Section III of this paper.

Again, the decisions that the MSC needs to make on this topic are an appropriate part of the Unified Sizing Criteria discussion and possibly the Credits discussion. It is clear that the problems associated with the collection, routing and treatment of snowmelt runoff will continue to occur unless we address the shortcomings of using our warm weather techniques to treat a cold weather problem. The outcome of this discussion should set the stage for finally addressing this problem in a scientifically sound manner.

V. PRELIMINARY CONSIDERATIONS FOR DESIGN SHEETS BASED ON COLD CLIMATE PERFORMANCE (EOR/CWP)

Applicability of BMPs for Cold Climate

Details on specific BMP design and maintenance will be part of the design sheets that will be prepared for Issue Papers "I" and "J" that will be presented in late spring 2005. Before that occurs, however, it is necessary to look at the list of BMPs identified in Issue Paper "A" and assess their applicability for cold climates to carry the selection process one step further.

The CWP (Caraco and Claytor, 1997) presented a preliminary classification of a number of BMPs relative to cold climate use. Table 3 is an adaptation of the original CWP table (Table 1.2 in the publication) adjusted for the BMP list in Issue Paper "A". Note that most of the BMPs listed were selected in Issue Paper "A" because of their potential for success in cold climates. For this reason, the classifications in Table 3 tend to favor their use.

Table 3. Applicability of Issue Paper "A" BMPs for Cold Climate Use.

BMP Family	BMP	Classification	Notes
Pollution Prevention	Housekeeping practices	Yes	Focus on rapid clean-up of paved surfaces after snow melts
	Atmospheric control	Marginal	Control of auto emissions and industrial output usually not under local control, but exposed winter soils are controllable
	Chemical controls	Yes	Salt management and chemical spill control can be local programs
	Animal waste management	Yes	Strict waste control can be covered in local ordinance
	Streambank stabilization	Yes	Attention to local erosion sites can reduce ice damage and sediment load from high spring flows
Runoff Volume Minimization	Natural area conservation	Yes	Preserving pervious areas for meltwater to infiltrate is effective way to control volume
	Soil amendments	Yes	Enhancing soil permeability will increase infiltration of meltwater
	Reduction of impervious surface	Yes	Preserving pervious areas for meltwater to infiltrate is effective way to control volume and to minimize mobilization of pollutants
	Grass drainage channel	Yes	Routing meltwater over a pervious surface will yield some reduction in flow and improved water quality
	Rain barrel/cistern	Marginal	Capturing meltwater from a building will reduce volume but ice build-up could be a problem unless collection occurs below frostline
	Permeable pavement/blocks	Yes	Recent research has shown this approach to be successful in cold climates when properly installed and maintained, and when sanding kept to a minimum
	Soakaway pit/drywell (designed so as not to qualify as a Class V injection well)	Yes	Effective as long as system is installed below the frostline to avoid ice build-up

BMP Family	BMP	Classification	Notes
	Stormwater planter	Marginal	These are designed more for the growing season, but they do provide a sump area for runoff to collect and will infiltrate some of the volume
	Rooftop garden	Yes	Recent research has shown that slow melting in the spring reduces the volume running off of roof surfaces
Temporary Construction Sediment Control	Pre-construction planning	Yes	Focus on sequencing to avoid open soils during winter and on limited grading prior to freeze-up
	Resource protection	Yes	Buffers reduce runoff by providing infiltration potential
	Runoff control	Yes	Stable drainageways and sediment basins assure erosion control and provide storage opportunities for spring meltwater
	Perimeter control	Yes	These practices are especially effective during winter construction
	Slope stabilization	Yes	These must be installed prior to freeze-up to be effective; they must be checked often and maintained all winter
	Stabilized soil	Marginal	Seeding, blankets and sprayed stabilizers must all be in place and working before freeze-up; if necessary, blankets can be laid and held in place with sandbags or rock logs
	Inspection and maintenance	Yes	Essential for proper operation all winter
Bioretention	Rain garden	Marginal	By definition, these are growing season practices, but they do provide a sump area for storage and some infiltration during a melt
	Depressed parking islands	Yes	These can provide needed storage during the cold season and for spring runoff events; vegetation will not be a factor during winter

BMP Family	BMP	Classification	Notes
Filtration	Media filter	Yes-to-marginal	Surface systems need to be fully dry before freeze-up for these to work properly; sub-grade systems can be very effective for meltwater treatment
	Surface vegetative filter	Marginal	Vegetative filtering is reduced once vegetation dies back in the fall; some physical filtering will occur if vegetation density and depth are sufficient
	Combination filter	Yes-to-marginal	See comments above
Infiltration	Trench	Yes with caution	Effective when designed, installed and maintained properly; caution applies to limitations on source area to avoid high concentrations of Cl and toxics
	Basin	Yes with caution	See above comment
Ponds	Forebay	Yes	Effective if designed with enough available volume to accommodate meltwater in the spring
	Storage components	Yes	Adaptations must be made to allow meltwater runoff to receive appropriate amount of treatment (see discussion following in this section); treatment effectiveness usually lower than warm weather
	Outlet	Yes	Proper design of the outlet structure can be the key to ponding effectiveness
Wetlands (constructed)	Forebay	Yes	See comment for forebay above
	Storage components	Yes-to-marginal	Volume will be less than typical pond, but provide location for storage, some infiltration, filtration and some microbial activity; biological activity at a minimum
Supplemental Treatment	Proprietary sediment removal	Yes	These devices are typically installed below ground and below the frostline, and can be effective in treating sediment-laden spring runoff

BMP Family	BMP	Classification	Notes
	Catch basin insert	Marginal	The location of these in a very cold location often leads to icing conditions; can be marginally effective for solids even if frozen
	Wet vault	Yes	See comment for proprietary devices
	Chemical treatment	Yes	These systems are designed to inject treatment chemicals for all flows
	Floatable skimmer	Yes-to-marginal	Proper installation of a floatable skimmer or baffle weir will allow water to pass even when thick ice is present; draws water from below ice layer
	Sorbents	Yes	These absorb chemicals usually in sub-grade systems
	Thermal protection	No	Do not apply to winter conditions
	Biological additives	Yes	See comment for chemical treatment

Adaptation Concepts

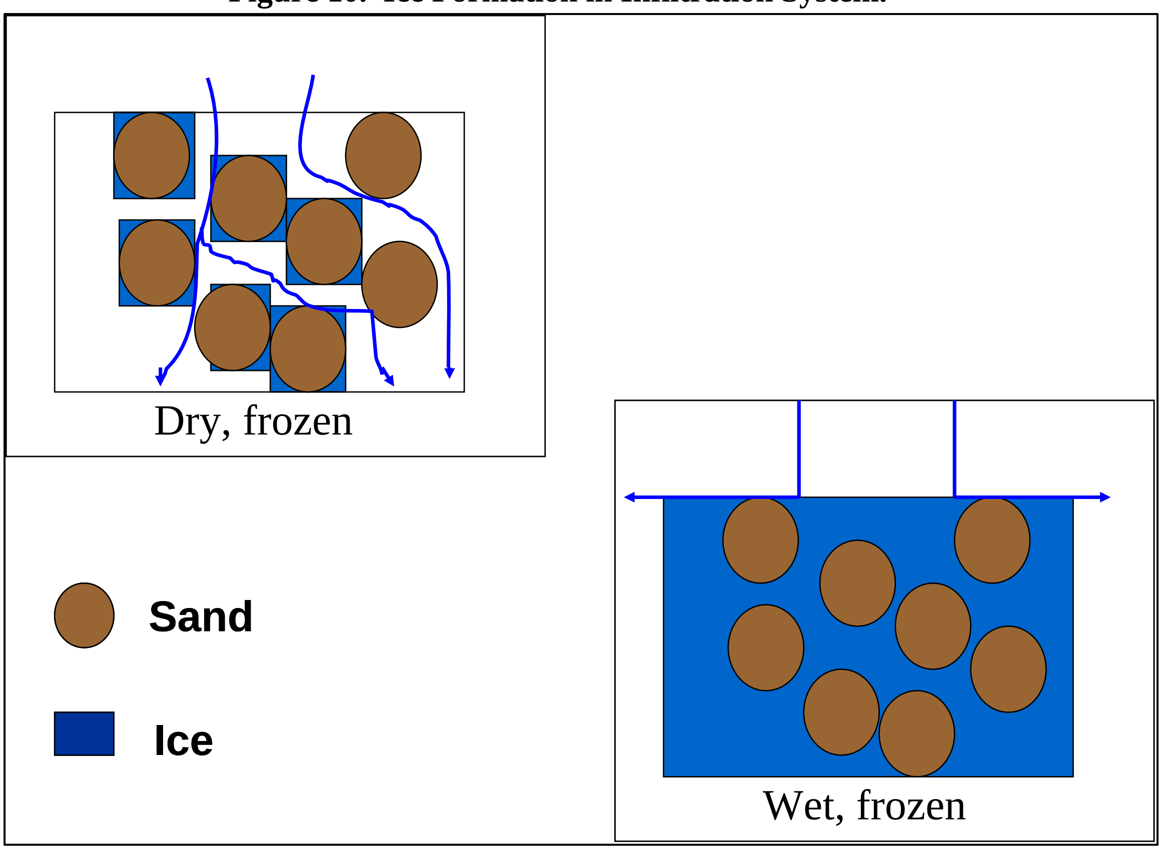
Each of the design sheets for the BMPs listed above will address adaptations needed to properly operate in cold climates. Following in this section, however, are some select adaptations for some of the structural systems. General concepts are discussed in this paper for the MSC to consider. If agreed upon, the details will be refined in later work for the Manual.

Infiltration Basin/Surface Filter

Various options for use of infiltration and filtration are available for treating meltwater. Some of the installations are built below the frostline (trenches, sub-grade proprietary chambers) and do not need further adaptation for the cold. Surface systems, however, do need some special consideration.

The problem with infiltration or filtration in cold weather is the ice that forms both over the top of the facility and within the soil interstices (Figure 10). To avoid these problems to the extent possible, the facility must be actively managed to keep it dry before it freezes in the late fall. This can be done by various methods including limiting inflow, under-drainage and surface disking.

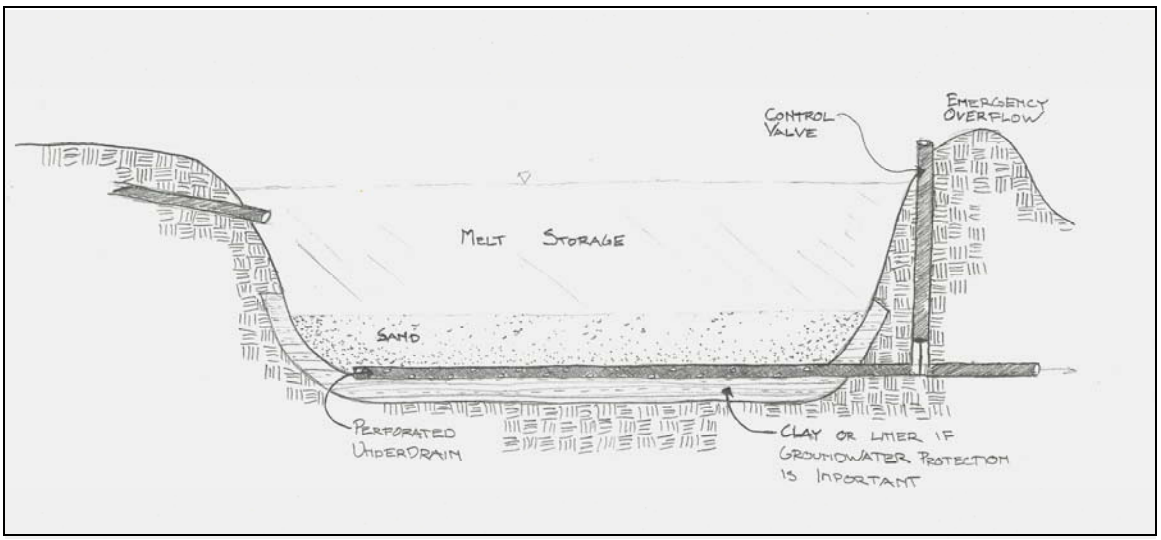
Figure 10. Ice Formation in Infiltration System.



Even if the infiltration properties of an infiltration basin are marginal for melt, the storage available in the facility will provide some storage if it is dry entering the melt season. Routing the first highly soluble portions of melt to an infiltration facility provides the opportunity for soil treatment (filtration, adsorption, microbial activity) of these solubles. Again, however, caution is stressed to not introduce flow originating in an industrial "hotspot" or a high traffic area where large amounts of salt are added. These source areas should be diverted away from infiltration systems.

Figure 11 is a general graphic portrayal of an infiltration basin adapted for handling spring meltwater runoff. The adaptation in this graphic is a sub-drain installed to dewater the basin of any water heading into the freeze-up. This drain can be closed just prior to meltwater inflow and during the non-winter seasons to allow infiltration to continue downward. Also note that a clay liner can be added if the need to protect local groundwater from infiltrating meltwater is important. If this adaptation is made, the basin is no longer an infiltration system, but instead becomes a filtration system or dry pond.

Figure 11. Seasonal Infiltration Basin (or filtration basin if liner added).



Proprietary, sub-grade infiltration systems provide an alternative to standard surface based systems. These systems, in essence, provide an insulated location for <u>pre-treated</u> meltwater to be stored and slowly infiltrated, or simply filtered and drained away if groundwater sensitivity is an issue. The insulating value of these systems adds to their appeal as low land consumption alternatives to ponds and surface infiltration basins.

In cold climates, stormwater filtering systems need to be modified to protect the systems from freezing and frost heaving. Physical design and operational considerations to keep in mind for filtration systems include:

- Freezing of the Filter Bed
  - Place filter beds for underground filters below the frost line to prevent the filtering medium from freezing during the winter.
  - Discourage organic filters using peat and compost media, which are ineffective during the winter in cold climates. These organic filters retain water, and consequently can freeze solid and become completely impermeable and less likely to thaw as quickly as other filters during the spring melt.
  - Combine treatment with another BMP option that can be used as a backup to the filtering system to provide treatment during the winter when the filter bed is frozen.
  - It may be feasible to construct the filter inside a structure to minimize likelihood of freezing.

- Pipe Freezing
  - Use a minimum 8" underdrain diameter in a 1' gravel bed. Increasing the diameter of the underdrain makes freezing less likely, and provides a greater capacity to drain standing water from the filter. The porous gravel bed prevents standing water in the system by promoting drainage. Gravel is also less susceptible to frost heaving than finer grained media.
  - Replace vertical standpipe with weirs, which are less likely to clog with ice. Although weir structures will not provide detention, they can provide retention storage (i.e., storage with a permanent pool) in the pretreatment chamber or within the primary treatment device.

- Clogging of Filter with Excess Sand from Runoff
  - If a filter is used to treat runoff from a parking lot or roadway that is frequently sanded during snow events, there is a high potential for clogging from sand in runoff. In these cases, the size of the pretreatment chamber should be increased to 40% of the treatment volume. For bioretention systems, a grass strip, such as a swale, of at least twenty-five feet in length and less than 3% slope should convey flow to the system.
  - Filters should always be inspected for sand build-up in the filter chamber following the spring melt event.

- Miscellaneous
  - There is a potential to manage snow as an insulating device, perhaps using a snow blower early in the season to insulate the filter bed. This practice will be more effective in regions where snow is on the ground continuously, rather than in regions with multiple melt events

In addition to the physical considerations to keep in mind, there are also water quality considerations which include:

- Avoid introducing any flow from areas with concentrated runoff likely to contain toxic chemicals such as chloride (salt), heavy metals, solvents, gasoline, and pesticides, or other polluting material such as nitrogen and phosphorus; and
- Always pre-settle solids to prevent clogging of the interstitial pore spaces in the infiltration bed material.

Note: Although filtering systems are not as effective during the winter, they are often effective at treating storm events in areas where other BMPs are not practical, such as in highly urbanized regions. Thus, they may be a good design option, even if winter flows cannot be treated. It is also important to remember that these BMPs are designed for highly impervious areas. If the snow from the contributing areas is transported to another area, such as a pervious infiltration area, their performance during the winter season is less critical to obtain water quality goals.

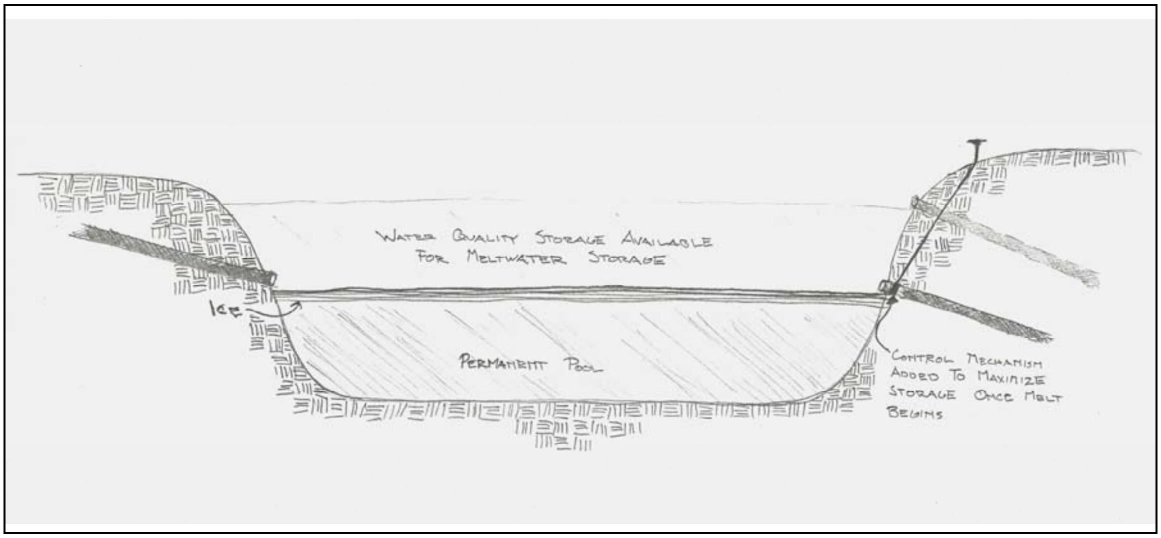
Seasonal Ponds

The difficulties of operating an effective storage and treatment pond in a cold climate were discussed in Section III (see Figure 9). Note within the graphic portrayal in Figure 9 that problems exist with the thick ice cover (lack of reaeration, "impervious" cover for settling purposes, reduced storage volume) and under the ice (anaerobic conditions, resuspension of settled material, concentration of Cl and toxic material, dissolution and density stratification).

To overcome the difficulties identified in Figure 9, some seasonal adjustments can be made to account for winter conditions. The obvious need in this situation is to eliminate the effect of the ice layer. This layer can be up to several feet thick during a hard winter and can greatly reduce the availability of the designed storage volume. The result is usually a small amount of the initial melt diving under the ice in a somewhat pressurized manner until all of the available capacity provided by limited uplift of the ice cover is filled. Following this, meltwater begins to flow over the top of the ice, which usually means outflow at the other end after very limited exposure to settling due to the "impervious" ice cover.

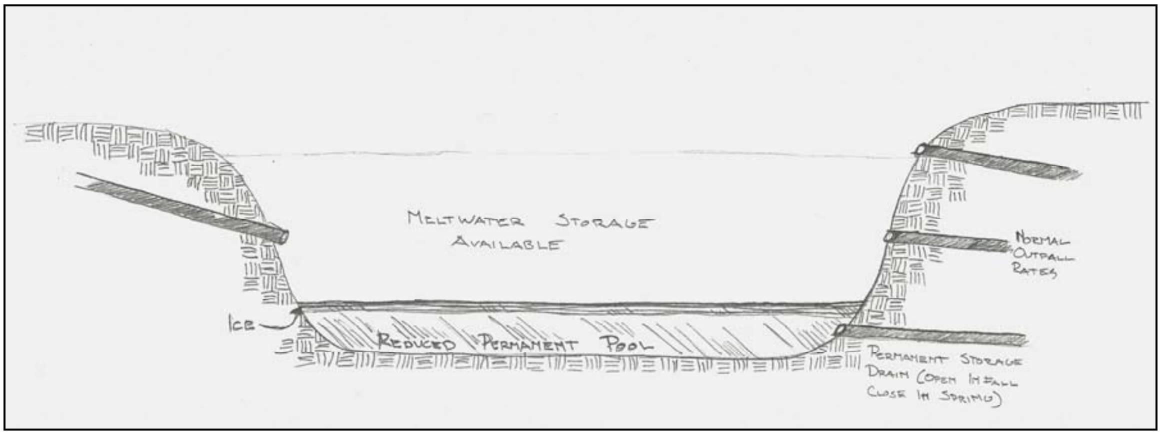
Minimizing the effect of the ice cover can be done passively through the design of surplus storage or actively through the management of water levels before ice has a chance to form and after meltwater inflow begins. The first suggested adaptation is shown in Figure 12. In this system, the normal design storage volumes are maintained, but a control mechanism (valve, weir, stop-log) is installed to reduce or even eliminate outflow for the normal water quality volume. This volume is then made available for meltwater, which can be held and slowly released. This approach provides for some settling time and could be used to capture high Cl flow for later slow release. The problems with under-ice build-up of anaerobic conditions and poor water quality will likely not be avoided under this adaptation.

Figure 12. Simple Meltwater Storage.



The second adaptation is one that should be used when concern over the quality of water associated with a pond is paramount. The adaptations in Figure 13 require more active management, but they will result in improved performance and fewer downstream water quality problems. This adaptation is especially recommended when sensitive receiving waters are a concern, or if additional treatment effectiveness is needed to achieve a TMDL requirement. The significant change made in Figure 13 is the addition of a controlled outlet mechanism for the permanent storage pool. Lowering this pool to a lower level will minimize the effect of an ice layer and maximize the storage available once the lower control is closed and the large spring melt occurs. The poor under-ice water quality concerns will be minimized. The "reclaimed" storage volume will equal most of the permanent pool and all of the water quality volume. The storage of all phases of the melt sequence shown in Section II means that solubles will be held, volume will be stored, and particulates will have a chance to both adsorb soluble pollutants and settle.

Figure 13. Lowered Permanent Pool Control.



One caution for this system is that the permanent pool could completely freeze or possibly disappear entirely if the drawdown is complete. Since maintaining a healthy biological system is part of a successful detention system, it is recommended that the permanent pool not be drawn too far down such that total freeze-up or elimination occurs.

The Importance of Baseflow, Inlet and Outlet Design in Ponds

Baseflow

The problems that develop under ice could be overcome in situations where baseflow is sufficient to keep the water refreshed enough to avoid anaerobic conditions and pollutant build-up. An assessment (in most cases a visual estimate) of the rate of inflow from baseflow expected over a winter could form the basis for establishing a drawdown level for the permanent pool. That is, the volume could be designed to be replaced on a frequency determined to avoid the depletion of oxygen and keep pollutant levels below toxic levels. Information on the source and characteristics of the inflow can also be important to pond design levels.

The total absence or occurrence of intermittent baseflow should favor a very low permanent pool level if an active management approach can be pursued.

Inlet and Outlet Design

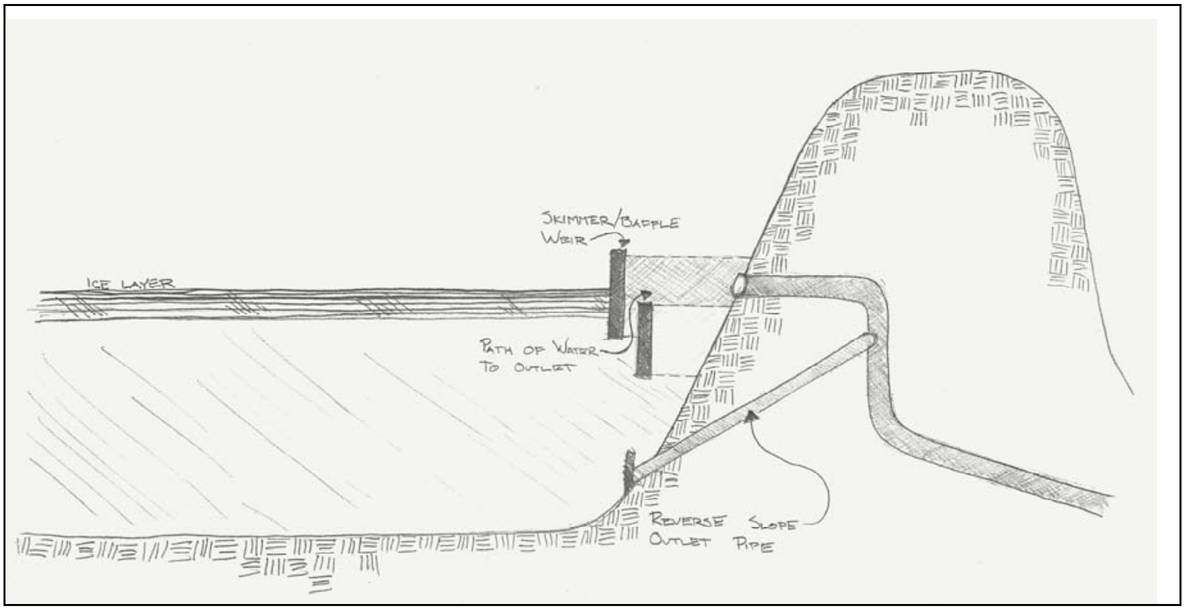
One of the biggest problems associated with proper pond operation during cold weather is the freezing and clogging of inlet and outlet pipes. To avoid these problems, the CWP (Caraco and Claytor, 1997) made some general design suggestions, which are adapted as follows:

- Inlet pipes should not be submerged, since this can result in freezing and upstream damage or flooding.

- Burying all pipes below the frost line can prevent frost heave and pipe freezing. Wind protection can also be an important consideration for pipes above the frost line. In these cases, designs modifications that have pipes "turn the corner" are helpful.
- Increase the slope of inlet pipes to a minimum of 1% to prevent standing water in the pipe, reducing the potential for ice formation. This design may be difficult to achieve at sites with flat local slopes.
- If perforated riser pipes are used, the minimum opening diameter should be ½". In addition, the pipe should have a minimum 6" diameter.
- When a standard weir is used, the minimum slot width should be 3", especially when the slot is tall.
- Baffle weirs can prevent ice reformation during the spring melt near the outlet by preventing surface ice from blocking the outlet structure.
- In cold climates, riser hoods should be oversized and reverse slope pipes should draw from at least 6" below the typical ice layer.
- Alternative outlet designs that have been successful include using a pipe encased in a gravel jacket set at the elevation of the aquatic bench as the control for water quality events. This practice was both avoids stream warming and is also a non-freezing outlet.
- Trash racks should be installed at a shallow angle to prevent ice formation.

Details on various outlet configurations are beyond the scope of this Issue Paper, but will be contained in future parts of the Manual. Some basic outlet concepts, however, should be mentioned. Perhaps as important as the layer of ice over the permanent pool is the blockage or hindrance of outflow from a pond because of a frozen outlet. There is a need to get water from under an ice layer to exit in a manner that does not cause splashing or gradual freezing of layer after layer of outflow. Drawing water from below the ice via a reverse sloped outlet pipe and installation of a skimmer device (baffle weir) that draws water from below the ice are two options shown in Figure 14.

Figure 14. Drawing Outflow Water from Below the Ice.



Bioretention

Table 3 noted that bioretention can be of marginal effectiveness for treating meltwater because of the dormancy of the vegetation during the cold season. However, the incorporation of some sump storage into the design of any bioretention system will provide an opportunity to route and collect meltwater and begin the filtration and infiltration processes. The only adaptation then that should be needed is the incorporation of some storage as part of the system. Once relatively "warm" meltwater begins to accumulate in a bioretention system, some downward migration will likely begin and the system will activate.

Vegetated Conveyance

Routing runoff over pervious drainage surfaces is a management method to promote the infiltration of water and reduce runoff volumes. Previous discussion in this paper described both the promise and the problems associated with these systems in cold weather. In essence, any infiltration should be considered an extra benefit, but the systems should not be relied upon during winter conditions to operate as well as they do during warmer weather.

Some considerations to keep in mind for these systems include:

- Use of salt tolerant plants if salt loads are high
- Annual removal of accumulated solids from road sanding

- If under-drained, increase the size of the pipe to a minimum diameter of six inches and a minimum one-foot filter bed
- Maintain soil bed permeability of swales at USCS Class SW or SM (NRCS, 1984) to encourage meltwater infiltration
- For culverts connection systems, use minimum diameter of 18” and minimum 1% slope
- Incorporate mulch or soil aeration to restore soil structure and moisture holding capacity damaged by salt and solids

Snow and Ice Management

Dealing with the accumulation, removal and disposal of snow and ice is not a stand-alone BMP, but rather it encompasses many public works practices that potentially impact on the quantity and quality of meltwater runoff. Practices are as variable as the number of governmental public works departments and commercial maintenance companies providing services. A small discussion on snow management and snow dump operation was presented in Section III. Some basic criteria for siting a snow dump were suggested, and further adaptations are not needed for this section. Local snow removal, however, does not usually involve collection and removal to a remote site. Rather, it is typically a matter of plowing to the side of the road or the far ends of the parking facility. Little thought is given to the fact that this snow will melt in the spring and flow into a receiving water or into a conveyance line that will flow to a receiving water.

Options for disposal of snow removed via neighborhood street and major roadway plowing are usually quite limited. The common Minnesota practice of pushing piles back from the paved surface as far as possible is encouraged. Research has shown that up to 90% of the pollution accumulated next to roadsides over the winter is deposited within about 25 feet of the road surface. Keeping the melt from this area off of the paved surface to the maximum extent possible is a positive water quality management strategy. Allowing it to soak into the ground is a good first step, followed by exposure of the melt to particulates in the roadside area so adsorption can occur.

Commercial and industrial areas that plow their parking and otherwise paved areas into big piles on top of the pavement could greatly improve the management of runoff it instead they dedicated a pervious area within their property for the snow. Even pushing the plowed snow up and over a curb onto a pervious grassed area will provide more treatment than simply allowing it to melt on a paved surface and run off into a storm sewer.

As mentioned previously in this paper, alternatives to NaCl for road salting are not currently feasible because of cost (high relative to NaCl) and secondary environmental effects (like high BOD). Until such alternatives become available, a wise-use ethic should be the goal of every salt user. Adaptations in equipment are always being evaluated by Mn/DOT, which continually updates its statewide fleet with improved equipment. Passing down its experience and knowledge on these improvements is an

important role for Mn/DOT. Adequate driver training on application methods and monitoring of driver salt use are other approaches to wiser salt use.

There has been a shift in recent years by many public works departments to reduction in anti-skid sand and greater use of salt. This shift has been propelled by the high cost of removing sand from street surfaces and stormwater conveyance and treatment systems. If this trend continues, the adverse impact of salt on Minnesota's receiving waters is likely to increase. As difficult as sand is to deal with, it is generally inert and can be easily removed. Salt is a conservative substance that readily migrates into soil, groundwater, lakes and streams, causing problems at each step along the way. A continued state program to reduce use, keep storage areas covered, educate salt handlers and improvement equipment is essential.

Finally, reduction in overall salt use has always been perceived as competing with driver safety. The progress made in more effective salt application techniques will hopefully be adopted by all applicators and show how the two important goals of environmental protection and driver safety can co-exist.

High Sediment Load

The addition of sand as an anti-skid agent to roads and parking lots can lead to the accumulation of sand in conveyance systems and pond inlets, as well as the plugging of infiltration and filtration systems. Frequent inspection of these facilities is essential, particularly in the early spring when large amount are washed from paved surfaces into runoff conveyance and treatment systems. Examining the need for clean-out of conveyance lines, dredging of forebays and ponds, and debris removal from infiltration/filtration systems should be a part of an annual inspection and maintenance program.

Many of the newly available proprietary sediment removal devices are intended to be installed below the frostline and, therefore, operate as designed under all weather conditions. These systems come with many different design approaches, but as a group they provide a very good method of pre-treating inflow into primary runoff treatment devices during the winter and spring runoff seasons.

Secondary Practices

There are some BMPs that are not generally recommended for water quantity or quality improvement because they are not as effective as other available techniques. There are situations, however, when these less used BMPs could have a possible cold climate role. One example of this is the use of dry detention ponds. These ponds have limited long-term water quality benefit, although there is some benefit from the fact that a portion of the stormwater infiltrates while it awaits outletting. A secondary benefit could be

achieved by routing overflow meltwater from a non-functioning practice into a dry detention pond to obtain even a small amount of infiltration and settling.

> **ISSUE #10** - Can routine rainfall runoff BMPs be adapted to work under the severe cold weather conditions experienced in Minnesota? If so, should the state expect these to be part of routine planning for management of runoff?

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VII. APPENDIX A: Annotated bibliography of recent references and conferences dedicated to cold climate water management

Eastern Snow Conference Series

Research into cold climate hydrology began in earnest in the U.S. with the activities of the Eastern Snow Conference (ESC - http://www.easternsnow.org/) in the early 1940s. This long and successful series of annual conferences continues today. This series has produced a myriad of papers that began the modern era of research into snow build-up and melt models.

The U.S. Army Cold Regions Research and Engineering Laboratory (CRREL)

CRREL (http://www.crrel.usace.army.mil/) also has a long history of studying the physical processes associated with snow, including the classic works of S.C. Colbeck and many others, helped to define the physics of snow accumulation and the movement of water and its contents from that snowpack after it melts. In 1966, a CRREL publication

(Bates and Bilillo, 1966) noted that nearly half of the land mass in the Northern Hemisphere, and essentially everything north of 40˚N latitude can be classified as "cold regions" based upon air temperature, snow depth, ice cover and frozen ground.

International Association of Hydraulic Engineering and Research
Meltwater runoff management has been the topic of several sessions at IAHR/IAWQ international conferences on urban storm drainage, including those in Banff in 1972, Gothenburg in 1984 and Niagara Falls in 1993. A 2005 cold climate session is planned at the August conference in Copenhagen.

International Conference on Urban Hydrology Under Wintry Conditions, March 19-21, 1990, Narvik, Norway
Proceedings from this conference are generally not available. Gary Oberts has a set of papers delivered at the conference, but a proceedings was not published. This was the first conference dedicated strictly to cold climate hydrology and water management. It brought together researchers from Europe, Japan, Canada and the US to present ideas on meltwater management.

Center for Watershed Protection's *Stormwater BMP Design Supplement for Cold Climates* (Caraco and Claytor, 1997) and revision session in Maine (2003)
This CWP publication was the product of a workshop held in St. Paul in the fall of 1997. The document is available from CWP at http://www.cwp.org/cold-climates.htm .

Water Environment Research Foundation's *Urban and Highway Snowmelt: Minimizing the Impact on Receiving Water*, by V. Novotny, D.W. Smith, D.A. Kuemmel, J. Mastriano, and A. Bartošová, 1999. WERF Project 94-IRM-2.
This WERF publication is a collection and synopsis of many pieces of cold climate research and data, primarily from the US and Canada. The focus is on highways, but the report is very informative on all aspects of urban cold climate runoff behavior.

UNESCO International Hydrological Programme, *Urban Drainage in Specific Climates - Volume II Urban Drainage in Cold Climates*, Edited by S. Saegrov, J. Milina and S.T. Thorolfsson, 2000. IHP-V, Technical Documents in Hydrology, No. 40, Vol. II.
This UNESCO report has a decidedly European focus, but in doing so, it collects many important research summaries and indications of the current state-of-the-art on cold climate hydrology and water management.

First International Conference on Urban Drainage and Highway Runoff in Cold Climate, March 25-27, 2003, Riksgränsen, Sweden and follow-up journal series in *Water Science and Technology*, Vol. 48, No. 9, 2003.
Researchers from predominantly the Scandinavian countries, Canada and the US presented a series of papers on cold climate water management. Many of the papers were published in the referenced *WST* periodical from 2003.

An International Conference - Stormwater Management in Cold Climates, November 3-5, 2003, Portland, Maine

This conference was a US version of the Riksgränsen conference referenced above. There was a markedly New England tone to the papers, but speakers from Canada and Scandinavia also presented. The CWP held a special session to receive input on revising its Cold Climate BMP Supplement, but funding for the reissuance has not been sufficient as yet. Although not all speakers prepared a paper, many are available for viewing and download at http://www.cascobay.usm.maine.edu/proceed.html .